Adaptive Networks with Dynamic DMA Topology

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‘Modelling a Path to Resilience’
Background

- The work presented here was undertaken by the InfraSense Labs (Imperial College London) and was part of Robert Wright’s PhD research project. Supervisors: Dr Ivan Stoianov and Dr Panos Parpas.

- The PhD was sponsored and supported by
District Metered Areas

- PRV
- Permanently closed boundary valve
Dynamic DMA Topology

- Lower frictional energy losses = More optimal PRV control = Reduced leakage
- Multiple supply paths = Improved resilience to failure
- Automatically revert back to original DMA topology

PRV
Bidirectional Control Valve (Dynamic Boundary Valve)
Dynamic DMA Topology

Advantages:
• Better resilience to failure (instant response)
• Lower frictional energy losses (therefore better pressure management achievable)
• Lower leakage
• Water quality improvements (remove dead-ends, flow reversal become normal and acceptable)

Disadvantages:
• More advanced modelling and control technology required
• Other water quality concerns e.g. exacerbate contamination
Experimental Study

- 2 DMAs with 8,000 properties
- Critical customers
- 2x Dynamic boundary valves & 3x PRVs, equipped with:
  - High speed pressure logging
  - Electromagnetic flow meter
  - Dual bypass at DMA boundary sites for bidirectional flow & control
  - Remote comms.
Experimental Study
Network Modelling

Pressure

Flow

Pressure
Control Optimization

\[ \text{minimize } f(\eta) = \sum_{j=1}^{n_n} \beta_j h_j \] (1)

Subject to equality constraints representing energy and mass conservation defined as:

\[ r_i q_i q_i^{-1} + A_{12,i} h + A_{10,i} h_0 + A_{13,i} \eta = 0, \ \forall i \in N_p \] (2)

\[ A_{12,j} q - d_j = 0, \ \forall j \in N_n \] (3)

and inequality constraints that represent a minimum service level on pressure and a requirement that PRVs regulate pressure in a single direction:

\[ -q_i \leq 0, \ \forall i \in N_v \] (4)

\[ -\eta_i \leq 0, \ \forall i \in N_v \] (5)

\[ h_{\text{min}} - h_j \leq 0, \ \forall j \in N_n \] (6)

h is the hydraulic head, i.e. we are minimising pressure.

Subject to constraints that describe the hydraulics of the network (i.e. the model).

And a limit on minimum acceptable pressure.
Simulated Results: AZP

AZP becomes identical when dynamic boundary valves close at night.

Based on 2 PRVs and 2 dynamic boundary valves.

Up to 7.7% reduction in AZP during the day when dynamic boundary valves open.
### Experimental Results: Leakage

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total DMA Input (Data)</td>
<td>19.9Ml</td>
<td>18.9Ml</td>
<td>17.8Ml</td>
</tr>
<tr>
<td>% Reduction compared to Phase 1</td>
<td>n/a</td>
<td>5.5%</td>
<td>10.9%</td>
</tr>
<tr>
<td>Total Leakage (Model)</td>
<td>4.38Ml</td>
<td>3.44Ml</td>
<td>3.19Ml</td>
</tr>
<tr>
<td>% Reduction compared to Phase 1</td>
<td>n/a</td>
<td>21.4%</td>
<td>27.2%</td>
</tr>
</tbody>
</table>

**Phase 1:** Closed DMA boundary and fixed outlet PRVs
**Phase 2:** Closed DMA boundary and flow modulating PRVs
**Phase 3:** Dynamic DMA boundary and flow modulating PRVs
Experimental Results: Resilience

1,400 properties maintain full, adequate & instantaneous supply through dynamic boundary valve.

Real burst, 35 inch trunk main

DMA Inlet 1 (Unaffected)

DMA 1

2\textsuperscript{nd} Dynamic Boundary Valve not yet commissioned

DMA Inlet 2 (Failure)

DMA 2

No supply
System Overview

Valve control optimization

Remote Control & Actuation

Data Processing & Modelling

Continuous High Speed Logging

Software

Hardware
• DMAs help water companies globally to reduce leakage

• But DMAs also inhibit the customers’ service, pressure management, and some aspects of water quality

• Dynamic DMAs could offer the best of both worlds

• But they require:
  o More technology
  o A greater understanding of the hydraulics of water supply networks
  o A better understanding of the benefits in relation to the costs
Thank You

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