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Event Management and Post Event Response Planning for Smart Water Systems

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Introduction

The water industry in the UK and worldwide faces considerable challenges in making effective use of sensor and other data that is collected in Water Distribution Systems (WDSs) in near real-time. This data is still not effectively utilised in a water company's control room, especially when it comes to identifying a suitable strategy to respond to failure events in near real-time. Relevant academic work has not adequately addressed this challenge mainly due to the focus on specific stages (i.e. isolation, impact assessment or interventions) rather than the overall response process. Furthermore, for an effective near real-time response there is still need for: 1) improved impact assessment methods (e.g. real performance indicators used in the water industry, including discolouration potential), 2) more realistic selection of operational interventions, 3) effective exploration of the operator's proposed response strategies together with the automatically generated ones and their respective impact and 4) improved visualisation of response strategies and their resulting impact to the operators. In this study, an overall response methodology that aims to fulfil the above need is proposed.

Response Methodology

The overall response methodology consists of the following main steps: Step 1) initial impact assessment (i.e. before any intervention is implemented), Step 2) a solution is proposed by the operator and Step 3) an optimal solution is generated ~~by~~ using optimisation. Note that these three steps do not need to be carried out in a sequential manner. The following three-stage routine is followed in each of the three steps: Stage 1) the operator inputs information/parameters into a decision support -type tool, Stage 2) hydraulic simulations are carried out and the impact for each solution is calculated and Stage 3) the calculated impacts are visualised. The response methodology is implemented into a decision support ~~-type~~ tool ~~- entitled the~~ Interactive Response Planning Tool (IRPT). IRPT links MATLAB software to the EPANET Programmer's Toolkit [1] to execute the overall response methodology proposed in this study.

In the IRPT, improved impact assessment is based on a number of indicators that are used in the UK water industry. Examples include: 1) the number of affected customers due to low pressure and supply interruption, 2) the undelivered volume of water due to low pressure and supply interruption, 3) the average low pressure duration and 4) the total discolouration potential increase. In this work, the impact is expressed in three ways: a) as single indicator impact (i.e. computed at each time-step of a user-specified impact horizon), b) as aggregated impact (i.e. single indicator impacts aggregated over the impact horizon; and normalised to account for the unit differences of different indicators, which is required for comparison purposes and to enable subsequent calculation of the total impact), and c) as total impact (i.e. weighted sum of the aggregated impacts for all indicators - see [2]). Another novel aspect of the IRPT is that it enables continuous interaction between a human and a machine to identify the 'best' response strategy (i.e. not always 'optimal' but that account for certain aspects that a computer cannot easily consider such as, for example, a valve that cannot be operated). In the IRPT, the human solutions are the response strategies proposed by an operator based on his/her own preferences and/or current system constraints. The machine solutions are the response strategies generated automatically as a result of Genetic Algorithm (GA) based optimisation. In this study, the optimisation problem aims at the minimisation of two objectives. The first objective is the total impact (see above) of a generated response strategy and the second objective is the number of interventions used in that strategy (which acts as a surrogate for operational cost of interventions). In the IRPT, realistic interventions are proposed to constitute the best response strategy, including: 1) isolation valve manipulations (i.e. opening/closing), 2) valve setting adjustments, 3) rezoning valve manipulations (i.e. opening/closing), 4) water injection and 5) combination of these. Water injection, which is a novel type of intervention considered in this study, is carried out through Alternative Supply Vehicles (ASVs). It is important to highlight here that apart from the type of interventions, the GA optimisation also identifies the optimum start times and duration for the different interventions. Through standardised visualisations, IRPT gives an operator the capability of selecting the preferred solution.

Case Study

The above methodology is demonstrated on the real network of B-City [3]. The failure event considered is a large burst event, which is assumed to be detected at 7 pm, on a main distribution pipe with a diameter equal to 600 mm.

In the overall response process presented here, the initial impact assessment (i.e. Step 1) is carried out first. Here the operator only inputs into the IRPT (Stage 1) information about the burst detection time (i.e. 7 pm) and the time horizon on which to calculate the aggregated/total impact (i.e. 24 hours in this example). Then the initial aggregated/total impact is calculated (Stage 2) and visualised (Stage 3), as shown in Figure 1a. Once this is done, it is assumed that the operator decides to propose his/her own response strategy (i.e. Step 2). In this context, the operator inputs into the IRPT (Stage 1) the following additional information: a) a possible isolation/repair duration (i.e. 6 hours in this example), b) the expected isolation start time (i.e. 4 hours after the pipe burst is detected in this example), c) the number of available ASVs (i.e. 2 in this example) which will inject water for 1 hour each and d) the start time of injection (i.e. 1 hour after event is detected in this example). Similarly to what was done in Step 1, the aggregated/total impact of the operator's proposed intervention strategy is calculated (Stage 2) and visualised (Stage 3), as shown in Figure 1b. Finally, it is assumed here that the operator decides to ask the support of the GA optimisation (i.e. Step 3). To achieve this the operator inputs into the IRPT (Stage 1) the following settings for the optimiser: a) the time window in which isolation is expected to start (i.e. between 2 and 4 hours after the event is detected in this example), b) the time window in which interventions are expected to start (i.e. between 1 and 3 hours after the event is detected in this example), and c) the maximum number of ASVs that can be used (i.e. 5 in this example). Following optimisation, a Pareto front of optimum solutions is obtained. Each solution has a certain calculated total impact (Stage 2). Here, for demonstration purposes, the aggregated/total impact of a solution which suggests that: i) isolation starts 4 hours after the event is detected, ii) all 5 ASVs are used and they start pumping water into the network 1 hour after the event is detected, iii) 1 throttle control valve is adjusted 1 hour after the event is detected and iv) 1 boundary (i.e. rezoning) valve is opened 1 hour after the event is detected, is visualised (Stage 3) in Figure 1c.

By comparing Figures 1a, 1b and 1c, it is possible to observe that the aggregated/total impact dramatically decreased for both the manual and optimised solutions. However, by comparing Figures 1b and 1c, it is clear that the number of affected customers and undelivered water due to low pressure are significantly lower in the optimised solution while the low pressure duration is only slightly larger. In this context, despite a larger number of interventions will have to be carried out (i.e. higher costs), the operator may select the optimised solution if priority is given to minimising the number of affected customers and/or undelivered water. If, however, priority is given to minimising the number of interventions or the minimisation of the low pressure duration is preferred then the manual solution may be selected.

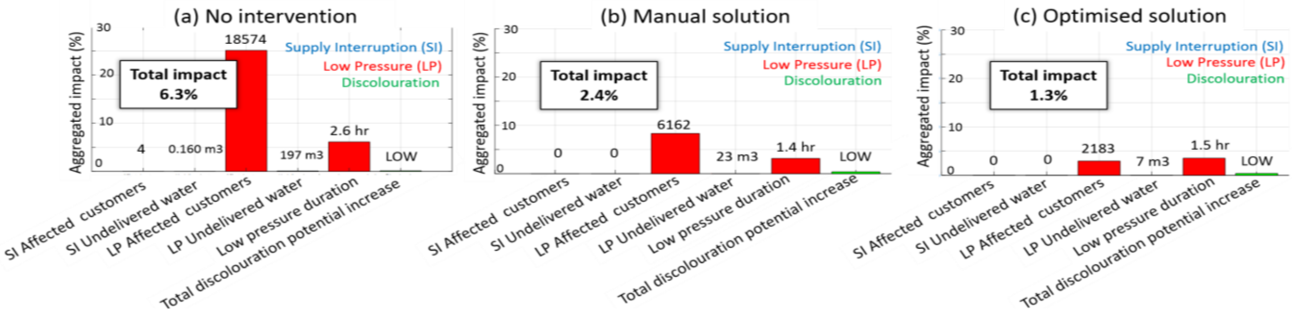

Figure 1: Comparison of the aggregated/total impact for no intervention (a), manual (b) and optimised (c) solutions

Conclusions

The research work presented in this paper attempts to improve on previous work focussed on near real-time response planning following failures in WDSs. This is accomplished by proposing a methodology which features improved impact assessment methods, makes use of realistic operational interventions, allows an effective exploration of operator's proposed and automatically generated response strategies together with their respective impact and develops improved visualisation of the response strategies/impacts to the operators to facilitate decision-making.

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