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Comparison between entropy and resilience as indirect measures of reliability in the framework of water distribution network design

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Abstract

The aim of this paper is to investigate which between the entropy and resilience indices represents a better indirect measure of reliability in the framework of water distribution network design. The methodology adopted consisted of (a) multi-objective optimizations performed in order to minimize costs and maximize reliability, expressed by means of one of the indirect indices at time; (b) retrospective performance assessment of the solutions of Pareto fronts obtained. Two case studies of different topological complexity were considered. Results showed that indices based on energetic concepts (resilience and modified resilience) represent a better compact estimate of reliability than the entropy.

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Keywords: entropy; resilience; reliability; water distribution network; optimal design.

1. Introduction

The reliability of a water distribution system is classically defined as its capacity to fully satisfy users' demand in a given period of time (Hashimoto 1982). For a *direct* estimation of service reliability several specific performance indicators can be adopted (Gargano and Pianese 2000, Tanymboh et al. 2001, Ciaponi 2009, Creaco and Franchini 2012), for instance expressing the average (or weighted average) of the ratios of water discharge supplied to users to the corresponding water demand under various operation scenarios, including normal peak

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operational conditions and critical operational scenarios such as segment isolation and hydrant service. The evaluation of these performance indicators may unfortunately turn out to be a computationally heavy task, especially in the case of complex real networks, since it generally implies the execution of numerous pressure-driven hydraulic simulations.

Therefore, in an attempt to limit the computation time (like in the context of network design phase, when reliability assessment has to be done several times), reliability is often expressed through *indirect* indices such as resilience (Todini 2000), modified resilience (Prasad et al. 2003) and entropy (Tanyimboh and Templeman 2000); these indices can in fact be evaluated by means of a single (even demand-driven) hydraulic simulation, in a bid to express the redundancy of the network under benchmark operation conditions.

It is thus of great interest to understand which of the above indirect measures of reliability is the most appropriate to better characterize the *full* reliability of the network within the framework of the design phase. In this context, Tanymboh et al. (2011) and Greco et al. (2012) investigated which indirect index is more correlated to network reliability. In their works the Authors generated various pipe diameter configurations in the case studies analyzed in order to obtain network featuring higher and higher values of the indirect reliability indices. Subsequently, they retrospectively assessed performance indicators for each of the configuration and analyzed the correlation between each indirect index and the performance index. In the end, Tanymboh et al. (2011) and Greco et al. (2012) arrived at contrasting results. As a matter of fact, by considering the retrospective assessment only of performance indicators related to segment isolation, the analysis of Tanymboh et al. (2011) indicates the entropy as the best indirect measure. On the other hand, Greco et al. (2012) indicate the resilience as the best indirect reliability measure.

This paper is aimed at analyzing in depth the issue of indirect reliability indices. Unlike the works of Tanymboh et al. (2011) and Greco et al. (2012), it considers the analysis in the framework of network multi-objective design (Gessler and Walski 1985, Todini 2000, Prasad et al. 2003), where the indices are related to the costs; furthermore, the comparison of the indices is made by retrospectively assessing performance indicators related to segment isolation and hydrant service, rather than only segment isolation.

In the following sections, the methodology is first proposed (section 2); then, the applications to two case studies of different complexity (a synthetic network and a real network) are presented (section 3) and conclusions are finally drawn (section 4).

2. Methodology

The methodology used in this paper consists of two steps. In Step 1, multi-objective design optimizations, aimed at simultaneously minimizing network total cost and maximizing a reliability indirect index, are performed on a water distribution network considering, as decisional variables, the network pipe diameters. The results of the optimizations are Pareto fronts of optimal solutions featuring increasing values of network cost and indirect reliability index.

Three different optimizations are performed using the NSGA-II multi-objective algorithm (Deb et al. 2002); the optimizations differ in the index adopted as indirect measure of reliability within the optimization process: optimization I – resilience index by Todini (2000); optimization II – modified resilience by Prasad et al. (2003); optimization III – entropy index by Tanyimboh and Templeman (2000).

In Step 2, in order to understand which of the optimizations (I, II or III) yields the best representation of the network reliability as the cost grows, for each of the optimization performed, all the optimal solutions of the Pareto front are *a posteriori* assessed in terms of direct performance indicators relative to the critical operation scenarios of network segments isolation and hydrant service, as proposed in Creaco and Franchini (2012). This retrospective assessment makes it possible to obtain relationships between the latter direct performance indicators and the costs produced by the different optimizations. Results are then compared and the best optimization approach, which leads to the highest reliability levels for given cost, is detected. The best optimization approach will give indication of which is the best indirect measure of reliability in the framework of network design.

In the following sub-sections, the indirect reliability indices (section 2.1) and the performance indicators (section 2.2) adopted are described.