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ScienceDirect

Procedia Engineering 186 (2017) 567 – 575

Procedia Engineering

www.elsevier.com/locate/procedia

XVIII International Conference on Water Distribution Systems Analysis, WDSA2016

Ranking alternatives for the flexible phased design of water distribution networks

João Marques[a]*, Maria Cunha[b], Dragan Savić[c]

[a] MARE – Marine and Environmental Sciences Centre, Department of Civil Engineering, University of Coimbra, Portugal.
[b] MARE – Marine and Environmental Sciences Centre, Department of Civil Engineering, University of Coimbra, Portugal.
[c] Centre for Water Systems, College of Engineering, Computing and Mathematics, University of Exeter, EX4- 4KF, United Kingdom.

Abstract

A multi-criteria decision analysis (MCDA) approach is proposed as a useful tool to support decision making in the phased design of water distribution networks over a long planning horizon. The criteria are evaluated for various design phases of the planning horizon and organised in four groups: investment costs, carbon emissions, pressure deficits and undelivered demand. Furthermore, a number of alternative designs, obtained by using optimisation techniques, are analysed for a number of different demand scenarios. The values of the criteria are computed and the alternatives are ranked by an MCDA method (PROMETHEE) to identify the best design solutions to implement according to different weights attributed to the criteria. The designs that best satisfy the most criteria are identified to be considered by the decision maker for the implementation in the first design stage.

Peer-review under responsibility of the organizing committee of the XVIII International Conference on Water Distribution Systems

Keywords: Water distribution networks; decision making; multi-criteria analysis; phased design

1. Introduction

Efficient design solutions for water distribution networks that take economic, environmental and quality of service dimensions into account and assume an uncertain future can be identified with the help of appropriate tools. Multi-criteria decision analysis (MCDA) is a transparent, structured approach that can be used in coherent decision

* Corresponding author
E-mail address: jmarques@dec.uc.pt

1877-7058
Peer-review under responsibility of the organizing committee of the XVIII International Conference on Water Distribution Systems
doi:10.1016/j.proeng.2017.03.271

making [1]. There are a few examples in the specialist literature of applying MCDA to water distribution network problems. Most of the literature in this area focuses on the analysis of alternative pipe replacement strategies for existing networks, as studied in [2] and [3]. The authors of this paper have also presented an MCDA for the reinforcement of existing water distribution networks with lack of hydraulic capacity [4]. Here, we introduce an MCDA to identify the best ranked alternatives for designing new water distribution networks, considering criteria evaluated for different phases. The alternatives and criteria are proposed according to a phased design scheme that enables the designer to adapt water networks if required. There is a gap in literature regarding the use of MCDA in the phased design of new water distribution networks. Therefore, the main purpose of this work is to show how the MCDA can help to identify the best ranked network design solutions from a number of alternatives and understand how preferences given to criteria at specific design phases influence the best alternatives to adopt.

The method proposed for solving the multi-criteria analysis is the preference ranking and organisation method for enrichment evaluation (PROMETHEE) developed by Brans and Vicke [5]. The use of this method in different areas is reviewed in [6]. It uses an outranking principle based on pairwise comparisons and requires the identification of different alternatives, criteria and weights to solve the problem. The results obtained with this method indicate the rank of the alternatives by computing a ranking index (*Phi*) to show decision makers a relationship between different options and help them to select the best. The rest of this work is organised as follows: section 2 sets out the methodology, section 3 describes the case study and presents the results and section 4 contains the conclusions and suggestions for future work.

2. Methodology

2.1. Scenarios building and criteria definition

Water distribution networks are planned to operate over long time horizons. Pipes installed are often in service for decades and many can function for more than a century. We propose making the decision-making process flexible by implementing phased design schemes that divide the planning horizon into phases and make it possible to intervene in the network at different times. The goal is to identify the network design for the first phase, keeping the whole planning horizon in mind and proposing reinforcing the network, if required, in future phases. As long-term predictions are highly uncertain, this work makes use of a set of synthetic demand scenarios generated randomly and with the same probability of occurrence for each time phase and between predefined minimum and maximum threshold limits. Furthermore, criteria are defined according to the planning phases. The idea is to evaluate the investment costs (this study considers only the capital expenditure costs CAPEX), carbon emissions, pressure deficits and undelivered demand independently for each phase. A cost criterion aggregating all investment costs in the planning horizon is also proposed to compare the overall cost of different alternatives. The present value of the total investment costs for all time phases is given by the criterion of Eq. 1 and the group of criteria of the investment costs for each time phase is given by Eq. 2.

$$CI_{tot} = \sum_{t=1}^{NPH} CI_t \tag{1}$$

$$CI_t = \sum_{i=1}^{NPI} \left(Cpipe_i(Dc_{i,t}) \times L_i \right) \frac{1}{\left(1+IR\right)^{y_t}} \quad t \in NPH \tag{2}$$

CI_{tot} – total investment cost *(USD)*
NPH – number of phases into which the planning horizon is divided
t – time phase (phase $t=1$ starts in year zero)
CI_t – present cost of investment for time phase t *(USD)*
NPI – number of pipes in the network
$Cpipe_i(Dc_{i,t})$ – unit cost of pipe i as function of the commercial diameter $Dc_{i,t}$ adopted *(USD/m)*
$Dc_{i,t}$ – commercial diameter of pipe i installed in time phase t *(mm)*
Li – length of pipe i *(m)*
IR – annual interest rate for updating costs