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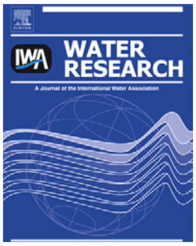

Replacement predictions for drinking water networks through historical data

Annika Malm [a,b,*], *Olle Ljunggren* [a], *Olof Bergstedt* [a,b], *Thomas J.R. Pettersson* [b], *Gregory M. Morrison* [b]

[a] *Gothenburg Water, Box 123, SE-424 23 Angered, Sweden*
[b] *Department of Civil and Environmental Engineering, Water Environment Technology, Chalmers University of Technology, SE-412 96, Gothenburg, Sweden*

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ABSTRACT

Lifetime distribution functions and current network age data can be combined to provide an assessment of the future replacement needs for drinking water distribution networks. Reliable lifetime predictions are limited by a lack of understanding of deterioration processes for different pipe materials under varied conditions. An alternative approach is the use of real historical data for replacement over an extended time series. In this paper, future replacement needs are predicted through historical data representing more than one hundred years of drinking water pipe replacement in Gothenburg, Sweden. The verified data fits well with commonly used lifetime distribution curves. Predictions for the future are discussed in the context of path dependence theory.

1. Introduction

Ageing of the drinking water distribution network implies a need for replacement strategies and the prediction of asset lifetime. The drinking water distribution network represents a major proportion of the investments and capital assets for a water utility. Therefore, informed knowledge about future replacement requirements provides water utilities with an assessment of future financial needs.

Asset lifetime of a distribution network can be described as the breakpoint in time when it is no longer socially and/or economically acceptable to choose acute spot repair, the alternative being to rehabilitate the ageing pipe. Marlow et al. (2010) describes several approaches for modelling remaining asset lifetime with the distinction between deterministic models, statistical models, physical probabilistic models and soft computing or artificial intelligence models. The statistical models are based on historical failure rate or service lifetime and other data. One of the statistical models is a cohort survival-based method where asset properties that influence the ageing behaviour, such as material and corrosion protection, are the basis for dividing assets into groups.

Cohort survival-based methods relate the age of the water distribution pipes to the expected lifetime expressed as

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* *Corresponding author*. Department of Civil and Environmental Engineering, Water Environment Technology, Chalmers University of Technology, SE-412 96, Gothenburg, Sweden. Tel.: +46 31 368 71 27; fax: +46 31 13 78 31.

E-mail addresses: annika.malm@vatten.goteborg.se (A. Malm), olle.ljunggren@vatten.goteborg.se (O. Ljunggren), olof.bergstedt@vatten.goteborg.se (O. Bergstedt), thomas.pettersson@chalmers.se (T.J.R. Pettersson), greg.morrison@chalmers.se (G.M. Morrison).

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a distribution curve. Various statistical distributions can be used for modelling probabilistic lifetimes of the water distribution network. Herz (1996) compared different statistical distributions and found that both the Weibull distribution and the Herz distribution (Herz, 1994) are suitable for predicting the ageing of pipes. Based on the Herz distribution, a Long-Term Planning software (Care-W LTP) for the prediction of service lifetime was developed in the Care-W project (Herz and Lipkow, 2003; Sægrov, 2005). This software is an extended version of the original KANEW software (Deb et al., 1998). KANEW is used in European and American cities (Sægrov et al., 2003). In Sweden Care-W LTP is used in Stockholm based on partly verified data (Stockholm Water, 2008; Meyer, 2007).

According to Marlow et al. (2010) cohort survival-based methods can only be applied to asset cohorts. One criterion for grouping assets into cohorts is based on a similarity in asset failure behaviour. Typical data requirements for asset cohorts are installation date (year, decade), failure history, pipe type and soil conditions. A cohort could be ductile iron pipes without corrosion protection in aggressive soil. In reality, the method has been used for installation year and pipe type and also, if needed, period laid, in Sweden (Grontmij, 2008; Meyer, 2007) and in Norway (König, 2001, 2006; Melina et al., 2008; Selseth and Røstum, 2003; Sægrov and Selseth, 2000; Selseth and Sægrov, 2001) rather than a complete dataset of diameter, failure history and soil conditions.

Age itself does not have a decisive influence on the optimal point in time to renew a single pipe. Pipe failure rate, which includes pipe breaks and leakage, depends on factors such as soil condition, laying methods and pipe material, and is shown to be the best criterion for optimal individual pipe rehabilitation such as renovation and replacement (Herz, 1998; Sægrov, 2005). However, age or remaining asset life is a useful criterion for strategic asset management (Burn et al., 2010) when the intention is to predict the rehabilitation needs for an entire drinking water distribution network. One important limitation for replacement prediction through historical data is areas that have recently been laid. Historically, new materials have almost always been considered promising and there will therefore be a tendency to overestimate their medium and long-term replacement needs.

Service lifetime models rely on pipe deterioration aspects to determine physical lifetime, although the socio-technical system changes over time are not included. Although asset condition is the most common criterion for rehabilitation (Sægrov, 2007), external factors such as change in water demand, large infrastructure projects and street or sewer pipe replacement can significantly affect the actual drinking water network rehabilitation (Malm et al., 2009; Torterotot et al., 2005). Fundamental processes of change can occur in the socio-technical drinking water distribution networks which in turn affect rehabilitation needs. Three types of change processes in a socio-technical system have been identified by Geels and Kemp (2007): reproduction, transformation and transition. Reproduction includes changes along defined paths, such as the use of new pipe materials. Transformation is changes at a regime and landscape level, including changes to visions, goals or guiding principles. Examples of transformation are climate change adaptation and changes due to microbiological issues. Transition is an expression of a major shift in a socio-technical system, an example being a change from individuals carrying water from an outdoor stand pipe to home water delivery through a pipe system.

Strategic decision making affects both the need for rehabilitation and the actual rehabilitation. This need is affected by the rehabilitation necessary for external decision factors, such as major infrastructure projects, or internal decision factors such as goals for acceptable failure rates. The actual rehabilitation can be affected by the economic preferences of the water utility such as investment plans where less (or possibly more) money than required has been allocated. In an interview study of 18 Swedish water utilities, the limitation for rehabilitation was as much the lack of human resources as the restriction of economic resources (Malm et al., 2009).

For drinking water network planning, knowledge about the effect of path dependent decisions through history allows confidence in making current decisions that will affect the future system. Kaivo-oja et al. (2004) describe the role of path dependence and decision making in the interaction between history and future research in the water sector, Fig. 1. Path dependence theory underlines the importance of history and emphasises that decisions made in the past have long-term impacts into the present and future (David, 2001). Past or traditional practice or preference provide a technology and/or infrastructure lock-in that prevails even if better alternatives are available (David, 2001). The impact of path dependence is due to binding, limiting or postponing alternative options (Kaivo-oja et al., 2004). The binding decision to develop a drinking water distribution system for the transport of water from source to tap is an example of strong path dependence. At present, when the distribution system is in place, and only smaller parts are rehabilitated at a time, the system remains unchallenged, despite concern over rehabilitation rates. One negative example of a limiting decision was the use of poor quality plastic pipes in the 1960s which has increased the need for rehabilitation. An example of postponing would be where no strategic planning is made and the rehabilitation is either too high or too low, or the wrong pipes are rehabilitated.

The lifetime of pipes differs between pipe material, laying method and decade. New pipe materials might be more robust than those used in the past, which in the long-term means a lower rehabilitation rate needed. However, if new pipe material does not prove as promising as anticipated, the rehabilitation rate will have to increase.

Cohort survival-based approaches require a substantial amount of data, otherwise assumptions are required and the predictive results can be imprecise (Burn et al., 2010). However, a satisfactory lifetime distribution can be estimated for a city or a region where annual data is available. The data may include present residual pipe length and age, network growth and past rehabilitation efforts.

The aim of this paper is to present a method for the prediction of future rehabilitation needs based on historical data. The method takes into account and analyses the influence of the decision basis for preceding rehabilitation rates. A second objective is to show whether a service lifetime based approach is trustworthy under conditions of data scarcity.