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Prediction Of the Future Condition Of A Water Distribution Network Using A Markov Based Approach: A Case study of Kampala Water

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Abstract

The increasing costs of managing urban water distribution systems coupled with limited budgets and new regulatory requirements has compelled water utilities to ensure that asset maintenance decisions move from a reactive to a proactive approach. This means that asset renewal decisions must shift from being made only when failures happen to well-planned priority- based replacement, repair and rehabilitation strategies. However the question of prediction of the future condition of the pipe network continues to trouble water utility managers because of the complexities in determining pipe conditions amidst poor data situations. Conventional approaches for prediction of pipe condition are skewed towards statistical analysis and do not consider failure history. Until now, there have been no approaches for prediction of future state based on pipe condition. This paper applies a Markov based approach as a decision support system to predict the future condition of a water distribution network. The approach is illustrated on a case study in Kampala Water, Uganda as a proof of concept. Data on pipe condition history per block is first checked to ensure it follows the Markovian process. Pipe condition has been based on a composite index that combines pipe age and break history. The goodness of fit has been evaluated using the X^2-inference test. The Poisson distribution has been used to develop transition probability matrices required to forecast the state future condition of the water distribution network. The approach will help water utility managers optimize maintenance and repair decisions amidst budget limitations whilst taking into consideration both current and future states of the pipe network.

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1. Introduction

In middle and low-income countries, deterioration and the rampant failure of water distribution networks is common. Much of the infrastructure particularly in Sub Saharan Africa which was installed in the colonial era (before 1962) has passed its end of the useful life. The funds availed for preventive pipe network maintenance is limited. For example Kampala Water alone spends an average of twenty five billion Uganda shillings per annum on only network repairs and maintenance [1]. Due to limited budget allocations, it is necessary to concentrate maintenance activities on those parts of the network where they are most needed. These funds are not sufficient because as the networks age, they deteriorate further leading to increased failure rates. Moreover levels of service and network efficiency (supply pressures, continuity of supply and Non-Revenue Water) have a relationship with pipe condition. Currently most water utilities find out about failures only when they happen. Consequences of unplanned failures include lost productions, damaging of other components and infrastructure and service interruptions [2]. In addition, a lot of water is lost before corrective action is taken. Predicting the future condition of the pipe network is required as a proactive strategy to determine the maintenance and repair requirements which will enable network managers to draw the necessary priority based maintenance schedules [3]. Studies have been done on predictive models to help prioritize inspection, repair, rehabilitation and replacement in water infrastructures. However a few studies [4,5] done regarding the use of Markov chains for the prediction of the future condition of water networks. However, they base on expert opinion for condition assessment which is highly subjective rather than on failure history.

Markov processes are used to model condition deterioration for infrastructure systems [5,6]. They are recommended for assets that pass several numbered condition states and passes from one state to another during each time step according to fixed probabilities [2]. A review of literature has revealed that Markov models have been widely applied to predict future states of many infrastructure systems. For example [7,8,9,10] applied the Markovian process on road and pavement management.[10, 6,11] applied the Markov model for the prediction of deterioration states of storm water and sewer pipes. A basic concept of implementing Markov decision process to the scheduling problem for infrastructure is suggested by[13]. Recently a few studies concerning the prediction of future condition and deterioration of water pipe deterioration using Markov chains have been carried out.[14] applied the Markov model to predict the optimal schedule for maintenance and improvement of a water system. The model applied dynamic programing and a Markov decision process to determine the optimal strategy based on cost. [15] modeled the occurrence of water pipe bursts with time based on a hidden semi-Markov model that uses a non-homogeneous Poisson process. The model was successfully applied to a Canadian distribution network with 1349 pipes and 5425 recorded failures. [4] presented an approach for predicting the deterioration of water pipelines utilizing a Markov chain process. The states modelled in the Markov chain are based on fuzzy logic. [4] applied Markov chains for the prediction of the future condition of water networks. However, the approach was only tested on large diameter pipes. Moreover the approach used expert opinion rather than on failure history to assess the condition assessment which is highly subjective. Although the aforementioned models have been applied on water networks, they are criticized for (i) being skewed towards modelling the deterioration of pipes without a failure history or which have been recently repaired (ii) using fuzzy and expert opinion that are subjective (iii) not being tested on a developing country context where water networks experience challenges such as intermittent supply and exhibit unique failure patterns. Moreover they have been applied on transmission mains and on large pipes with diameters greater than 500mm and with low failure rates. This work proposes the use of historical failure data to predicting the condition of a water distribution network using a Markov chain methodology

2. Case study description

The case study is made up of four blocks located in Mbuya, Nakawa Branch in Kampala Water, the largest branch of National Water and Sewerage Corporation that serves the Kampala Capital City Authority and surrounding Wakiso and Mukono Area. The blocks have been selected for because of availability and completeness of data. The blocks are 2129, 2130, 2030, and 2029 and constitute of 13 pipes of 3170 m. Information captured for each block relates to pipe diameter, location in terms of the block, the date on which the failure was reported and that on which