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Analysis of risk management methods used in trenchless renewal decision making

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ABSTRACT

The substandard condition of wastewater systems in the US, accompanied by the lack of financial resources for renewal are hindering adequate operation and maintenance of deficient sewer systems. Information about current and future pipe condition, as well as information about the impact of possible pipe failures are an integral part of an efficient asset management program and can help stakeholders make the best decisions to prioritize rehabilitation and/or replacement projects. Typically, pipes in the worst structural conditions are prioritized and budgeted within the capital improvement project planning. To be able to predict future pipe conditions, many methods have been developed and successfully implemented that incorporate pipe inspection data to predict the future state of these assets. Additionally, methodologies exist for determining the consequences of pipe failures economically, socially, and environmentally. These methods have been incorporated into decision support systems (DSS) that help utility managers determine when to rehabilitate or replace their assets. DSS for trenchless pipe renewal allow utility managers to determine the most suitable method to renew their assets, given known defects in the pipe. The aim of this paper is to provide a review of risk management methods that allow pipeline managers to estimate likelihood of failure and quantify consequence of failure of sewer pipes. Additionally, an updated review of existing DSS for trenchless pipe rehabilitation is presented and analyzed. Finally, recommendations are made to improve existing methods to make the risk management process for trenchless rehabilitation decision making more efficient and practical.

1. Introduction

Prioritizing pipe rehabilitation, renewal and replacement projects is a fundamental task of water and wastewater utilities that have to maximize the efficiency of their yearly allocated budgets to provide the required level of service to their customers. But with the continuous aging of the water and wastewater infrastructures, and the underfunding of these systems in the US (ASCE, 2017), it is challenging for utilities to keep up with the maintenance and expansion of their water and wastewater assets. To improve and to meet the needs of the continuously growing population, the Environmental Protection Agency (2010) estimated that approximately $271 billion are needed for the wastewater infrastructure over the next 25 years (Sterling et al., 2010; ASCE, 2017).

To address the need for sewer pipe inspection, maintenance and renewal, a variety of prioritization tools have been developed and are currently being used by utilities to identify pipes that have the highest risk of failure. Determining a pipe's risk of failure involves two basic steps: determining its likelihood of failure and determining its consequence of failure. Likelihood of failure involves determining the probability of a pipe to fail at some time in the future. Failure, in the case of a sewer pipe, can be defined as the condition rating of a pipe that is no longer structurally acceptable, the event where a maintenance action takes place, or any other way that suits the needs of the utility. To make these predictions, statistical tools are employed that make use of existing historical pipe condition inspection data. Consequence of a pipe failure, however, is a more complex component that involves several factors that need to be evaluated. Upon an unforeseen sewer collapse, the consequences related to such an event have an impact on the environment, society and the utility, more specifically the finances of the utility that manages those assets. By determining the risk of failure of all sewer pipes within a system, a ranking of the most critical assets can be done to prioritize inspection and renewal plans.

There aren't many tools available for selecting the optimal technology for sewer pipe renewal as there are for critical asset prioritization, as described above. Most of the DSS developed for this purpose are concentrated in three areas: (i) using expertise of designers and in-house engineers for municipalities and utilities, (ii) using tools

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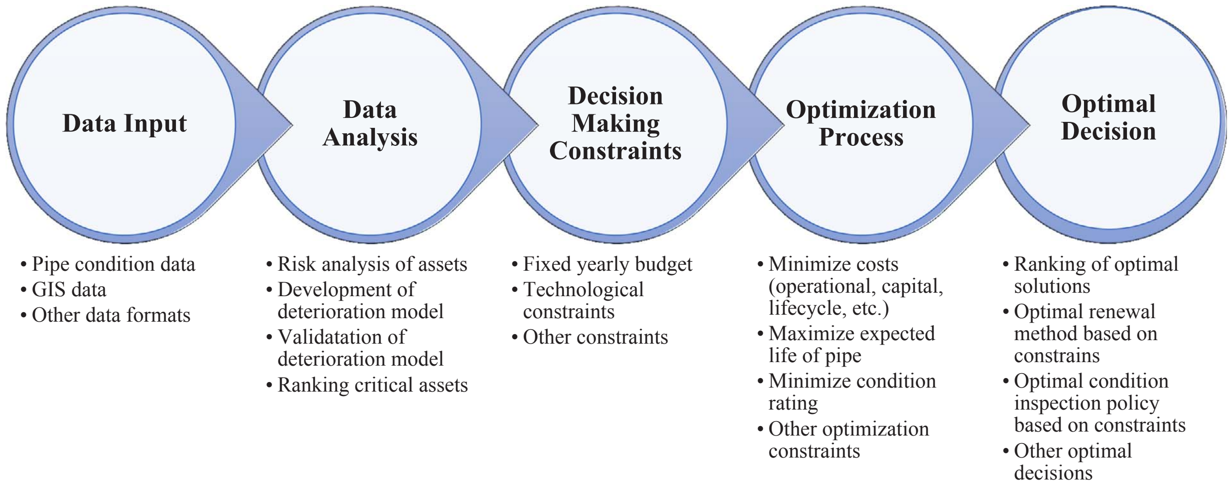

Fig. 1. Decision making process for pipe renewal.

developed by consulting firms for municipalities, which are proprietary, in most cases, and (iii) internally developed tools (Matthews et al., 2011).

The decision making process for trenchless sewer pipe rehabilitation involves several complex tasks that cannot be captured by one single model or method. The uncertainties related to random physical, economic, social, environmental, and technological parameters require an extensive decision making tool that is able to capture the variability of the system. As a result, comprehensive DSS have been developed with the purpose of capturing the complexity of the process and helping water utility managers and stakeholders in their decision-making process of sewer pipe renewal.

A simple overview of the decision-making process for pipe renewal is presented in Fig. 1. An efficient DSS should yield the optimal solution based on a series of constraints applied to a deterioration model developed based on the input data. The process should flow from inputting the data into the system to determining the most at-risk assets and giving an optimal inspection and renewal schedule for those assets, given a series of constraints. Section 6 of the paper presents more details about the decision making process, methods and tools.

2. Pipe failure and deterioration modeling

There several works in the literature that critically review the research in the area of pipe failure and deterioration modeling. Some of the most significant reviews are those by Kleiner and Rajani (2001a, 2001b), Liu et al. (2012), Nishiyama and Filion (2013), and St. Clair and Sinha (2012). The aforementioned reviews focus on statistical deterministic and probabilistic failure models, as well as describing advanced models such as artificial neural networks and heuristic models (St. Clair and Sinha, 2012), and provide a detailed description of the most important models and techniques developed in the past 35 years. The review of Scheidegger et al. (2015) discusses these models from a unified perspective and provides model assumptions, clarifications, data assumptions, type of published probabilistic predictions, as well as software implementations of the applicable published works. The objective of this paper is not to provide a detailed review of statistical pipe failure and deterioration models, but to review methods and tools used during the decision-making process of pipe rehabilitation, repair and replacement, from estimating likelihood of failure and consequence of failure of sewer pipes to planning and selecting the renewal technology (see Fig. 1). Therefore, the reader is strongly encouraged to refer to one of the aforementioned papers for a detailed review.

Usually, pipe failure (or break) models are useful to predict water main failures where inspection data contain historical break events. Deterioration models are useful for large diameter transmission mains and wastewater pipes, where current condition of the pipe is described by means of a condition rating system. As a result, historical deterioration data is collected over time, which then can be used for developing various deterioration curves and predicting future conditions of the analyzed assets. The type of model used strongly depends on the availability of historical failure or deterioration data, and the type of data collected (i.e. either pipe breaks over time, or condition deterioration of individual pipe segments over time).

The common method to inspect and determine the internal condition of sewer pipes is by video (CCTV). To determine the structural state of a pipe, a relevant, repeatable and validated methodology must be employed (Opila, 2011). By using a condition rating system, the visual inspection data from CCTV inspection is translated into an easily understandable and manageable form, which then can be used for prioritizing rehabilitation needs within the system (Kley et al., 2013). Additionally, by using a standardized condition rating system, the pipe condition data can be benchmarked and used within and across utilities. By using the same condition rating system, deterioration models and DSSs can be developed using the same data options.

2.1. *Sewer pipe condition rating systems in the USA*

In the United States of America, the accepted industry standard for sewer pipe condition evaluation is the Pipeline Assessment and Certification Program, or PACP, developed by the National Association of Sewer Service Companies, NASSCO (NASSCO, 2007). The PACP condition rating system uses pre-established capital letters as codes to assess the sewer pipe's defects. Each PACP code is also assigned a condition grade based on the severity of the defect. A 1–5 grading scale is used to assess the structural condition of the sewer pipe, and a typical time to failure is also provided for each condition grade, as presented in Table 1.

An Overall Pipe Rating is computed by adding all condition grades

Table 1
PACP condition scoring scale (NASSCO, 2007).

Grade	Description	Typical time to failure
1	Minor defect grade	Unlikely to fail in the foreseeable future
2	Minor to moderate defect grade	Unlikely to fail for at least 20 years
3	Moderate defect grade	Failure might occur in 10–20 years
4	Significant defect grade	Failure will most probably occur within 5–10 years
5	Most significant defect grade	Failure occurred or it is likely within the next 5 years