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Thesis title:
Sewer asset management – sewer structural deterioration modeling and multicriteria decision making in sewer rehabilitation projects prioritization

Thesis summary:
Sewer systems are an integral part of the urban water infrastructure due to their function (e.g. ensuring better public health and providing protection against flooding). In addition, these systems are capital-intensive in nature. Unfortunately, many sewer networks are undergoing aging and deterioration, which undermine their structural integrity. This results in failures and collapses and the accompanying difficult and costly emergency repair works. To avoid such occurrences, proactive management – as opposed to reactive management – is advocated as a better strategy to manage sewers. This type of strategy can be achieved by implementing an infrastructure asset management system, which allows for the efficient operation, maintenance and rehabilitation of the sewer networks through informed and structured decision-making.

In order for an infrastructure asset management system to succeed, tools are required related to the following key components of the system: (1) the ability to predict the deterioration of the infrastructure and (2) the ability to prioritize maintenance and rehabilitation projects in an optimum way. This research work tries to address the above issues. In particular, this research aims to: (1) investigate the most reliable sewer structural deterioration model and (2) develop a decision tool based on multicriteria decision-making (MCDM) techniques for the prioritization of sewer rehabilitation projects.

A survey of literature reveals that several techniques are being used in modeling the structural deterioration of sewers. These techniques range from physical models to artificial intelligence-based and statistical-based models. These models can further be subdivided into pipe group and pipe-level models. The former consider entire networks or cohorts, while the latter deals with individual pipes. Pipe group models are used in forecasting the deterioration of the sewers at the population or group level and are useful in the strategic management of sewers (e.g. estimating budgets for maintenance and rehabilitation works). On the other hand, pipe-level models are used for predicting the deterioration of individual sewer reaches, thus more useful in optimizing operational plans (e.g. prioritizing pipes for closed-circuit TV (CCTV) inspections and maintenance works).

Among the pipe group models are the cohort survival and semi-Markov models, while among the pipe-level models are the logistic regression analysis, multiple discriminant analysis (MDA) and probabilistic neural network (PNN). Key to the developments of these models is the availability of data on sewer condition and age, and data on the factors influencing the deterioration of the structure.

These models were developed and applied to the Leuven and Antwerp sewer networks in Belgium. The aim of which was to investigate their applicability and usefulness in modeling the structural deterioration of the sewers in the two networks and, ultimately, to determine the most suitable model among the techniques. The models were evaluated based on the following issues: 1) model theory, 2) forecasting power, 3) robustness of results and 4) model parsimony.

The investigation reveals that among the pipe group models, the cohort survival model is the most suitable. The merits of this model lie in its simple theory, its ability to forecast and its parsimony.

However, the model is sensitive to changes in calibration sample size. On the other hand, the semi-Markov model, although also simple in theory and parsimonious, was found to be unsuitable for deterioration modeling as it exhibited a very low forecast ability. Meanwhile, the pipe level models were found to be inaccurate. Although the logistic regression analysis and PNN showed good to high overall prediction efficiency levels, they were found to be susceptible to bias in predicting the conditions of sewers with the greatest number of samples in the calibration dataset. In addition, these models were also found to be unreliable for forecast modeling as they are capable of producing absurd predictions, such as predicting a sewer to improve in condition, as it gets older. In the context of sewer asset management, following such model could lead to potentially catastrophic decision, e.g. not rehabilitating a very old sewer, which is predicted to be in condition state, when in fact the sewer is already collapsing. Thus, care has to be observed in using these models for asset management purposes. One of the biggest challenges in the development of the sewer deterioration models is the availability of sufficient and quality data (or lack thereof).

For those deteriorated sewers, there is a need to rehabilitate them to keep their integrity – structural, hydraulic and environmental – at par with standards. Historically, however, the budgets allocated for sewer rehabilitation are low against the requirements. Thus, utility asset managers need to prioritize the competing projects. In the context of infrastructure asset management, prioritizing infrastructure projects is typically done using risk analysis or on a purely financial basis. However, the decision on which sewer rehabilitation project to prioritize is far from being straightforward. There are two basic reasons for this: 1) sewer rehabilitation programs need not only to consider several perspectives – such as structural, hydraulic and environmental aspects – but also financial aspects; and 2) the conflicting interests and priorities of different decision makers (DMs) and stakeholders – administrators, politicians, engineers. In cases such as this, the use of MCDM techniques is advocated.

In this research, an MCDM technique called ORESTE has been applied to the Brussels sewer network for the prioritization of its sewer rehabilitation needs. The method was selected due to its simplicity and the fact that it does not require the quantification of criteria weights and alternatives, rather only their ordinal rankings. This method is demonstrated considering 43 sewer rehabilitation projects and 16 criteria representing the following issues or points of view: structural, hydraulic, environmental, coordination, financial, technical, social and administrative. The application has demonstrated the use of the ORESTE method in providing a structured, rational, consistent and objective approach to complex decision problems such as in the prioritization of sewer rehabilitation projects. The novelty of the application is the addition of robustness analysis to the ORESTE algorithm. The inclusion of the robustness analysis allowed for the quantification of the uncertainties associated with the solution provided by ORESTE. This type of information is very important in developing confidence among DMs as to their decision on the priority ranking of sewer rehabilitation projects.

This research study is seen to contribute to the development of two important aspects of sewer asset management. On the one hand, the research presents a very important step in the development and use of sewer structural deterioration models based on the cohort survival model, semi-Markov model, logistic regression analysis, MDA and PNN. Through this type of study, much needed experience is gained, which is useful in building confidence in the use and application of these models. In particular, this study was able to determine the applicability and usefulness of the abovementioned models. On the other hand, the research was able to demonstrate the successful use of MCDM in prioritizing sewer rehabilitation projects. Specifically, the research demonstrated how simple MCDM techniques can be used successfully in forming sound decisions in a complicated decision making process, such as the prioritization of sewer rehabilitation projects. The experience gained in this work is important in providing confidence to the asset managers in the use of MCDM techniques. In terms of methodology, the research demonstrates the use of robustness analysis as a way to quantify the uncertainties in the ORESTE solutions. As far as the author knows, this represents an innovation in such application.