Louisiana Tech University

TRENCHLESS TECHNOLOGY CENTER

Development of a Wastewater Pipe Deterioration Model for Risk-Based Decision-Making

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Outline

- Introduction
- Brief overview of Markov Chain Models
- Continuous Time Markov Chain Model Used in This Study
- Model Application
- Results
- Model Limitations
- Conclusion

Introduction

- Deteriorated wastewater infrastructure
- Wastewater utilities need to prioritize renewal efforts to maximize resources
- Risk-based decision-making involves determining:
  - Probability of Failure (POF)
  - Consequence of Failure (COF)
- Determine Risk of Failure (ROF) as a combination of POF and COF

Introduction – cont'd

- Determine current and future conditions of wastewater pipes for an efficient asset management program
- Wastewater pipe deterioration models are vital
- In this study:
  - Continuous Time Markov Chain (CTMC) deterioration model using limited historical condition assessment data
  - Application: A U.S. wastewater utility

Markov Chain Models

- Determine the probability of moving from a current, better condition, to a future, worse condition (i.e. deteriorating over time)
- Discrete time (DTMC) vs. Continuous time models (CTMC)
- In the literature, most often DTMC is used
- Deterioration happens continuously, even if it is not continuously observed, therefore a CTMC approach is warranted

Continuous Time Markov Chain Model Used in This Study

- Three conditions a WW pipe can be in, at any time

- Deterioration rates (q) from better to worse conditions can be determined from condition inspection data
- Improvement is not possible; once a pipe is rehabbed/replaced, it is taken out of the system
- New condition assessment data is necessary to determine the deterioration rates of the rehabbed/replaced pipe material

Continuous Time Markov Chain Model Used in This Study – Cont'd

- To find the transition probabilities from better to worse conditions:

$$P(t) = \exp(Qt) = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ 0 & p_{22} & p_{23} \\ 0 & 0 & p_{33} \end{bmatrix}$$

Where $Q = \begin{bmatrix} -q_{12} & q_{12} & 0 \\ 0 & -q_{23} & q_{23} \\ 0 & 0 & 0 \end{bmatrix}$

- P(t) = transition probability matrix at age *t* of the pipe material (changing), calculated as shown
- Q = transition rate matrix (constant), determined from the historical condition assessment data of the analyzed network

Model Application

- Data was obtained from a U.S. WW utility located in Louisiana
- Selected pipe cohort: 48 km of 200 mm VCP installed in 1965
- Available information: one time CCTV inspection data from 2016, pipe characteristics information such as material, length, diameter, and age, and a series of other parameters such as flow control, pre-cleaning method, and location of pipe.

Model Application – Cont'd

- Determining the condition of each pipe segment was done using a condition rating model (part of doctoral dissertation)
- Two conditions for each pipe at times:
  - t=0 (time of installation, 1965 - assumption)
  - t=51 (time of only recorded televised data collection, 2016)
- Transition rate matrix, Q, was determined with this data (R software)

Results

- Constant transition rate matrix, Q:

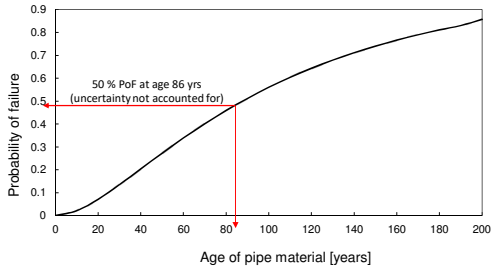
$$Q = \begin{bmatrix} -2.4980 & 2.4980 & 0 \\ 0 & -0.5167 & 0.5167 \\ 0 & 0 & 0 \end{bmatrix}$$

- Transition probabilities at any age of pipe can be obtained
- For example, one-year transition probabilities (t=1):

$$P(1) = \exp\left(\left(\frac{1}{51}\right)Q\right) = \begin{bmatrix} 0.952 & 0.047 & 0.001 \\ 0 & 0.989 & 0.011 \\ 0 & 0 & 1 \end{bmatrix}$$

Results- Cont'd

- 200-year probability of failure of 200 mm VCP pipe (8-inch)



Model Limitations

- Large time gap between inspections, 51 years: a shorter time span would improve the reliability of the obtained transition rates
- Model validation could not be performed; an additional inspection is required for that (so need for more good quality data)
- More than two inspections at shorter intervals would be useful
- Probability of failure is determined for a pipe cohort, and not for individual pipes – depending on the application of the model, this might be a limitation

Conclusion

- WW pipe deterioration was modeled on a continuous time scale
- Limited historical condition data was used
- Two condition inspections at minimum are needed to develop the model
- Additional inspection is needed to validate the model
- Combining the obtained POF with the COF determined the pipe's ROF, which can be used for decision-making purposes

THANK YOU!

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