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Theory Manual
Module 1 – Pipe ranking

AUTHORS: Benjamin Shannon, Guoyang Fu,
Ravin Deo, Rukshan Azoor, Jayantha Kodikara.
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Prepared by: Guoyang Fu

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INTRODUCTION

Monash University were tasked to provide lining innovations to enhance market uptake, including a standard and code of practice of use for CIPP liners and spray liners for pressurised pipes in the CRC-project. This was conducted by undertaking literature reviews, field trials, laboratory testing, and numerical modelling. The research findings were implemented into a standard and code of practice for use in the Australian water industry. A decision tool known as the "Monash Pipe Evaluation Platform" was developed to provide guidance to water utilities, applicators and liner manufacturers in the form of an online web-based platform.

The Monash Pipe Evaluation Platform is split into four modules:

1. Pipe ranking

2. Pipe failure analysis

3. Liner selection

4. Lined pipe analysis

Each module provides tools to help the users to make decisions on pipe rehabilitation.

Module 1 uses a pipe ranking approach to determine the most suitable pipe candidates based on failure history. This pipe ranking module allows the user to rank and prioritise pipes based on the Monash pipe ranking model or input final results from a utility specific ranking process. The following document examines the theory used for the Monash pipe ranking model.

1   PIPE RANKING MODELS

1.1   Monash pipe ranking model

The Monash Pipe Ranking Model uses the Bayesian simple model (Chik *et al.* 2017) to rank pipelines based on their probability of failure determined from past failure history.

In the Bayesian simple model, pipes are first grouped based on the number of known past failures. Then the failure probability for pipes in the same group are estimated. Each pipe in the group is given the same failure probability.

Assuming that the probability of failure for the pipes with k failures are independent and identically distributed using a Bernoulli distribution, the probability of observing a set of outcomes for the pipes with k failures given the failure probability θ_k is given as follows (Chik *et al.* 2017) (Equation (1)):

$$P\left(z_{k,1}, z_{k,2}, \cdots z_{k,n_k}|, \theta_k\right) = \prod_{i=1}^{n_k} \theta_k^{z_{k,i}} (1-\theta_k)^{1-z_{k,j}} = \theta_k^{\sum_{i=1}^{n_k} z_{k,i}} (1-\theta_k)^{n_k - \sum_{i=1}^{n_k} z_{k,i}} \tag{1}$$

$$P(\theta_k|\alpha,\beta) = \frac{\theta_k^{\alpha-1}(1-\theta_k)^{\beta-1}}{B(\alpha,\beta)} \tag{2}$$

$$P\left(\theta_k|\alpha,\beta,z_{k,1}, z_{k,2}, \cdots z_{k,n_k}\right) = \frac{\theta_k^{\alpha+\sum_{i=1}^{n_k} z_{k,i}-1}(1-\theta_k)^{n_k - \sum_{i=1}^{n_k} z_{k,i}+\beta-1}}{B\left(\alpha + \sum_{i=1}^{n_k} z_{k,i}, n_k - \sum_{i=1}^{n_k} z_{k,i} + \beta\right)} \tag{3}$$

$$E\left(\theta_k | \alpha = \frac{1}{2}, \beta = \frac{1}{2}, z_{k,1}, z_{k,2}, \cdots z_{k,n_k}\right) = \frac{\sum_{i=1}^{n_k} z_{k,i} + \alpha}{n_k + \alpha + \beta} = \frac{\sum_{i=1}^{n_k} z_{k,i} + 0.5}{n_k + 1} \tag{4}$$

where $P(\cdot)$ =probability of failure; k =number of failures a pipe has experienced in the past, pipes with the same number of known past failures are grouped together; $i = i$-th pipe with k failures; n_k =total number of pipes with k failures. It is the prior distribution, which represents the initial belief or assumption on the failure distribution for pipes with k failures. θ_k is assumed to follow a beta distribution with parameters α and β (Equation (2)), $B(\alpha, \beta)$ is the beta function with parameters α and β, $E(\cdot)$ is the expected probability of failure and $z_{k,i}$ represents whether the i-th pipe with k fialures have failed ($z_{k,i} = 1$) or not ($z_{k,i} = 0$) in the current year (the last year of the training data).

To estimate the probability of failure (posterior distribution) for the next year, it is straightforward since the beta distribution is a conjugate distribution for the Bernoulli distribution. The posterior distribution is a beta distribution (Equation (3)). The assigned value for the parameters in the beta distribution corresponding to the Jeffreys prior, are $\alpha = 0.5$, $\beta = 0.5$ (Gelman et al. 2000), and the expected probability of failure for a pipe in group k can be calculated by substituting the values into Equation (4).

1.2   Utility specific approaches

Different utility approaches and the model ranking results can be implemented into Module 1. For further details please see "User manual Module 1 -– Pipe ranking" document (UM M1 - Pipe ranking).

The Monash Simple Model and utility specific approaches for pipe ranking are data driven methods/approaches and typically do not consider any pipe deterioration processes (e.g., corrosion, fatigue, etc.). "Theory Manual Module 2 – Pipe failure analysis" (TM M2 – Pipe failure analysis) goes into detail about pipe deterioration for better pipe condition estimations.

CONCLUSIONS

This document provided the theory of the Pipe ranking models used in the Monash Pipe Evaluation Platform.

REFERENCE

Chik, L., Albrecht, D., and Kodikara, J. (2017). Estimation of the short-term probability of failure in water mains. *Journal of Water Resources Planning and Management*, **143**(2): 1–10.