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# Modelling Pipe Deterioration or Defect Evolution?

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## Introduction

Deterioration models are crucial for estimating the sewer pipe condition when comprehensive or up-to-date data is unavailable. Traditionally, these models focus on an overall pipe condition based on aggregated defect conditions. Few studies, such as Jimenez-Roa et al. (2022), Elmasry et al. (2017) and Stanić et al. (2014) examined failure mechanisms based on individual defects. This study explores whether examining defect evolution and transitions provides deeper insights into deterioration processes. By analyzing defect transitions in repeatedly inspected sewer pipes, it seeks to uncover relationships between defects, to identify potential aging patterns. Ultimately, the goal beyond the scope of this study, is to integrate these insights into deterioration models. For simplicity, pipe characteristics (e.g., age, material) are assumed to have a minor impact on defect transitions and are excluded from this analysis. The data was provided by Berliner Wasserbetriebe and all analyses are done in R.

## Methods

Inspection data from multiple assessments at least one year apart were combined into 18,166 inspection pairs. For pipes with more than two inspections, all possible combinations were analyzed. Time differences between inspections were distributed as follows: 1–5 years (18%), 6–10 years (47%), 11–15 years (21%), and 16–20 years (14%). Only inspection pairs showing the same or worse condition, with no repair, renovation, or renewal performed, were included. Defects were assessed at identical positions in the same pipes across these pairs. Selected defects (listed in Table 1) met two criteria: (1) sufficient occurrences during paired inspections and (2) potential to lead to other defects or degrade over time. An adjacency matrix was constructed for all defect pairs across positions and pipes and transition probabilities derived (see Figure 1). These Probabilities were filtered using a cut-off value of probability $\geq 0.25$. A knowledge graph was then created to show transitions, including the average time to subsequent defects.

**Table 1**. Selected defects for further analysis

| Codes | Description | No. of defects | Perc. of defects |
|---|---|---|---|
| BAA | deformation | 7,799 | 0.01 |
| BAB | fissure/crack | 259,768 | 0.29 |
| BAC | break/collapse | 20,242 | 0.02 |
| BAJ | displaced joint | 310,764 | 0.34 |
| BBA | roots intrusion | 310,982 | 0.34 |

## Results and Discussion

Figure 1 presents transition probabilities between defects, while the knowledge graph in Figure 2 adds the average time between inspections for these transitions. Self-loops in the graph and diagonal entries in the matrix represent the likelihood of a defect persisting into the second inspection. Root intrusion (BBA) was the most frequent defect, with a high probability of following various other defects. Displaced joints (BAJ) were also common but rarely transitioned to other defects, except for roots. The graph illustrates some reasonable transitions, such as deformation to fissure to roots. However, the transition from break/collapse to fissure remains unclear due to the undefined extent of these defects. The lack of defect characterization and quantification allows broad interpretations, especially for complex cases like break/collapse. Additionally, condition assessments may include uncertainties, hidden defects, or coincidental overlaps. While the knowledge graph captures average time spans, it omits discrete intervals, such as the continuous occurrence of roots, limiting temporal precision.

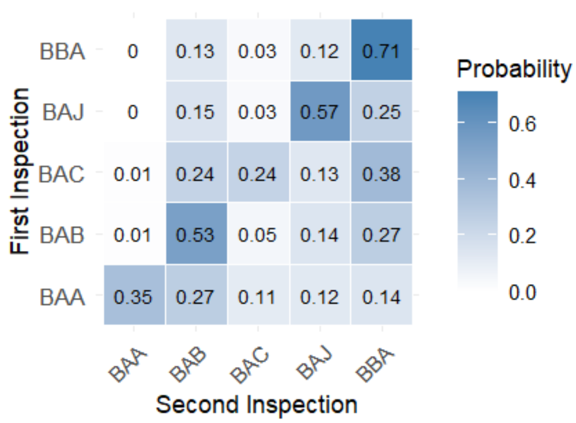


*Figure 2: Transition probability matrix between defects of inspection pairs for all time intervals*

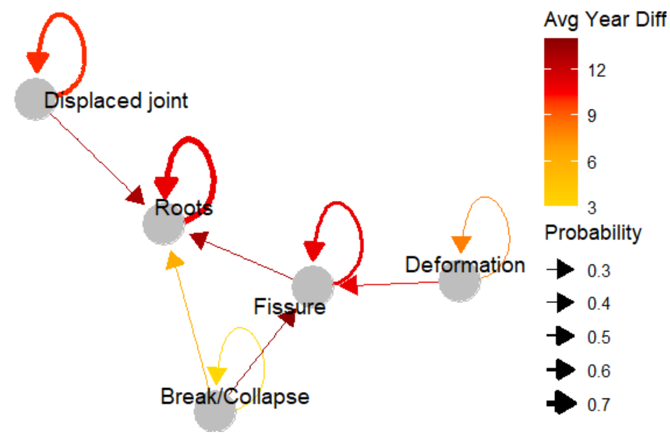


*Figure 1: Knowledge graph of defect transitions between inspection pairs, showing average years (color) and probabilities (line thickness)*

## Conclusions

This study presents the first analysis of multi-inspected sewer pipes and observed defect transitions, introducing a methodology not yet widely explored. The first results demonstrate that such an approach provides valuable insights into the aging process. However, the mentioned limitations highlight the need for further analyses. Future analyses will incorporate defect characterization and conditions to also analyze their transitions and to finally using these insights for more comprehensive deterioration models, at either pipe- or defect-level.

## References

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**Key words**: sewer pipe deterioration, defect evolution, inspection intervals, knowledge graph

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