Building a risk-based investment plan for drinking water mains

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Predicting the technical end of life allows to establish the risk of failure in a data-driven way. The presented methodology creates transparency in the trade-off between risk, financial and operational performance.

Among other things, data-driven research promotes informed and nuanced decision-making for the optimum operation, maintenance and investments in the pipeline network. Having an insight into the probability and impact of failure of individual pipes enables a budget level to be determined and from there, an associated performance level can be derived.

Access to safe, high quality drinking water is a fundamental human right incorporated in Article 11 of the United Nations International Covenant on Economic, Social and Cultural Rights. Companies that supply drinking water have a duty to ensure that customers have access to this essential basic supply. For a good drinking water supply, water companies depend on the condition of their network. This network is made up of transmission pipes that carry large volumes of water to the areas where the water is consumed, after which distribution pipes bring drinking water directly to the customer via household connections.

The pipes within the water supply network consists of various materials of varying quality, installed at different times. Ageing of these pipes creates the risk that leaks will occur more frequently or, worse still, simultaneously. This results in an increase in the number of unplanned interventions. To avoid this, it is necessary to understand the degradation of the pipeline network such that timely interventions can be scheduled. With these insights into the degradation behaviour of pipes, a forecast can be made as to the remaining lifetime, which allows an estimation of the required investments to meet certain performance criteria.

Rationale

In this article, Vitens and consulting firm Deloitte present the approach and results required to achieve risk-based long-term planning for the replacement of nearly 50,000 kilometres of pipelines, spread across five provinces. 5.9 million customers are supplied with drinking water through these pipes. The distribution network can be described according to classifications by material and construction date, as shown in figure 1. It should be noted that PVC and PE are the most common material types and are invariably used for the construction of new pipes. Older pipes, installed before 1980, show a higher proportion of asbestos cement and grey cast iron.

First, this article describes which data related challenges needed to be addressed. Data provides crucial input for gaining insights into the degradation behaviour of pipes. Next, a distinction is made between leaks that occur throughout the lifetime of a pipe and 'failures' that are indicative of structural or technical degradation. This failure definition is used in a subsequent section to model the remaining lifetime. It also describes how to translate the remaining lifetime into a risk per pipe. This risk is used to create a long term investment plan. The article concludes with a number of takeaways from this study.

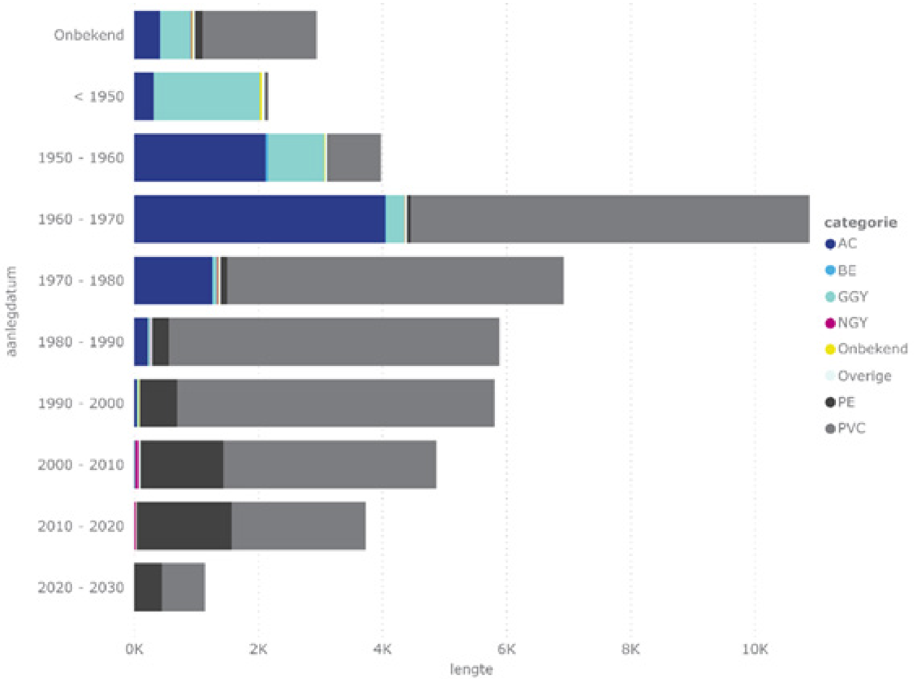

Figure 1. Breakdown of the distribution network by material and year of installation

Data related challenges

In this study, a number of data related challenges needed to be addressed:

- Data registration: although leaks are now directly linked to pipes, this was not the case in the past. Therefore, a methodology had to be developed to assign the right leak to the right pipe. Administrative interventions have also been carried out (e.g. the administrative splitting of pipes into smaller segments while physically still being the same pipe).
- Missing data: failure to track historical data is a problem that applies to both the year of construction, which is usually missing for older pipes, and pipes that have been removed and whose dates are not consistently tracked.
- External data: a wealth of information is available in the public domain regarding external data and more specifically environmental factors (soil type, vegetation, etc.). A methodology was developed and applied to enrich the data with these environmental factors, After all, these environmental factors can play an important role in degradation behaviour.

The data driven method is explained in more detail later in this article. As data driven methods are subject to the 'Garbage In, Garbage Out' principle, users of the results need to be aware of the quality of the data and the assumptions that have been worked with. In this study, data quality was measured using two dimensions: completeness (were all data fields completed, regardless of the value entered?) and accuracy (were the correct values entered?).

From leaks to failures

As stated in the introduction, the focus here is on the technical lifetime of a pipe. The technical lifetime can be seen as the lifetime during which an asset is able to continue to perform its function properly. It should be distinguished from, for example, the financial lifetime, which is determined on the basis of a depreciation period.

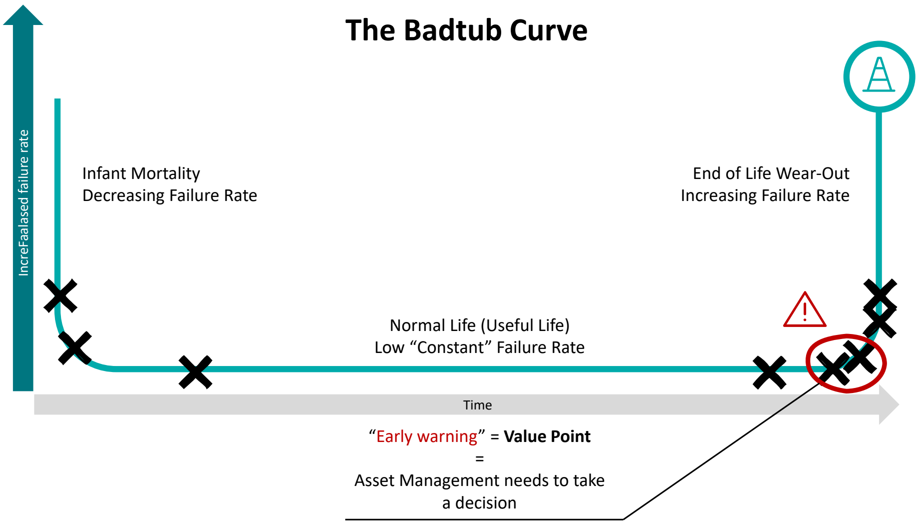

Figure 2. The bathtub curve showing an increase in leaks on the right. This is usually the time when an Asset Management decision regarding the pipe (e.g. replace, do nothing) needs to be made

A frequently used way of approaching the technical lifetime is the 'bathtub curve' (see Figure 2). This shows the expected progression in the number of leaks throughout a pipe's lifetime. A couple of leaks may occur at the beginning of a pipe's lifetime (for example due to installation errors), after which there is stability in a pipe's operation with only sporadic leaks. However, the occurrence of a leak is not necessarily a sign of degradation and the impending pipe's end of life. If multiple leaks occur over a short period of time and at short distances from one another, this may be an indication of a pipe's approaching end of life. At this point in time, a decision needs to be made from an asset management point of view (e.g. do nothing, replace as part of other combined works, etc.). This 'early warning' is the foundation for the approach discussed within this article.

The repeated occurrence of leaks within a short period of time and a short distance from each other is called a failure. This study has searched for a failure pattern that meets the above definition. To do this, we moved away from the notion of an individual pipe segment and introduced the concept of asset units. These are groups of pipes that are physically connected with each other and share common characteristics, such as their status (in use/not in use), material type, diameter, year of installation, etc. Clustering pipes into asset units resolves the challenge discussed earlier regarding the administrative splitting of pipes. By applying this clustering step, we work with 279,592 asset units instead of 692,702 pipes.

An appropriate failure pattern in line with the bathtub curve is then established at the level of asset units. To this end, some assumptions are made to exclude issues such as infant mortality. For example, leaks occurring within 15 years of the installation date are not included and asset units must contain three or more leaks. Also, leaks are assumed to be causally related if they are in close proximity to each other, both in terms of time (the time between successive leaks) and space (the distance within which leaks occur in the same asset unit). The parameters for timeframe and distance are varied (up to a maximum of 6 years and 800 metres, respectively) and applied to each pair of leaks within the same asset unit. Based on this analysis, the definition of a failure emerges.

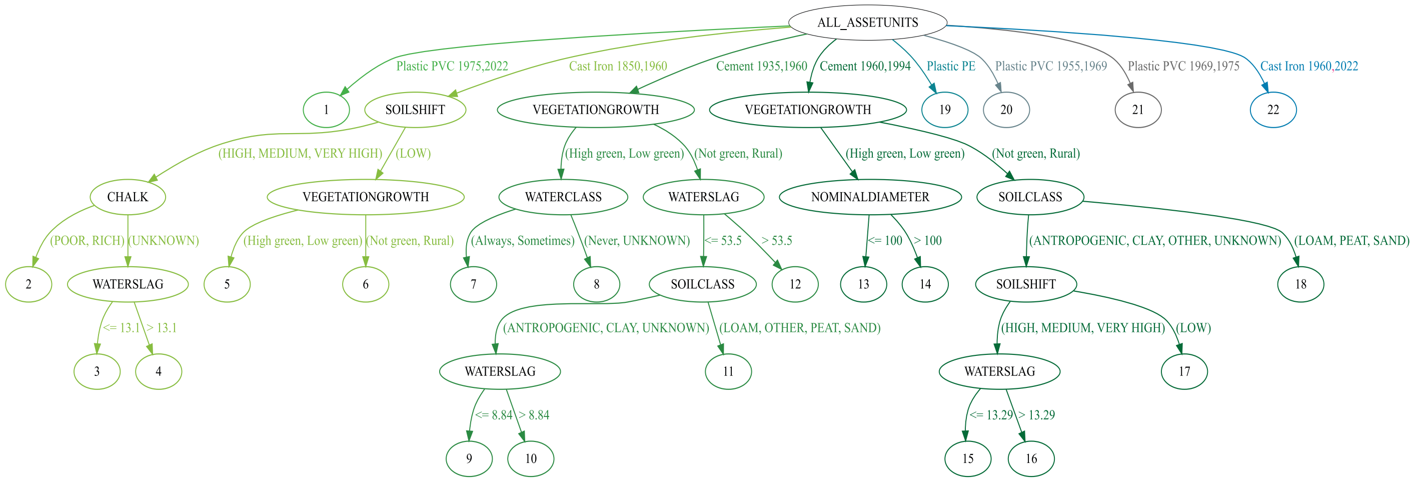

Figure 3. Tree structure in which all asset units are divided into 22 asset cohorts

Defining remaining lifetime

To proceed with modelling the technical lifetime, geographical characteristics are linked to the asset units. In this way, a check can be carried out to see whether, in addition to technical factors (such as material type and diameter), geographical factors (such as the presence of vegetation and calcium) also influence failure behaviour.

The modelling is based on a technique called 'survival analysis', which predicts the expected length of time until a failure occurs. Using a Machine Learning algorithm, all asset units are split into different groups based on their correlation with the occurrence of failures. Splitting continues until there is no significant relationship between the attributes and failure behaviour or there are too few remaining asset units in a group. The result is the classification of all asset units into 22 different groups, called asset cohorts, which represent different lifetimes based on their failure behaviour (see figure 3).

It should be noted that not all cohorts are split. For PE for example no split is made because too few failures have been observed on these asset units. Hence, a default value is used based on the Vitens' expert knowledge. However, as the pipelines age, a larger proportion of asset units will fail, so this branch of the 'tree' will likely be split and a reliable estimate can be made. This immediately demonstrates the added value of a self-learning algorithm that comes up with refined insights as additional data on failures and assets is ingested.

> Risk cannot be considered as an isolated element, but must be balanced with the required costs and the expected level of performance. There is no such thing as a risk-free network.

Figure 4 not only shows the average lifetime of a cohort, but also the spread in expected lifetime. The graph shows that for the material 'cement', constructed between 1935 and 1960, cohort 7 would have an average lifetime of 84 years. This means that if a pipe with cohort 7's characteristics is constructed today, it will last 84 years on average. In addition, the methodology works on the basis of conditional probabilities: for example, an asset that is already 60 years old will age beyond the average of 84 years because it has already reached the age of 60 years. This means that a reliable statement can be made about the remaining lifetime of an asset at different points throughout its lifetime. There is a degree of uncertainty about this estimate of the average lifetime, as the historical data from Vitens has to be extrapolated. Specifically for cohort 7, the degree of uncertainty is about 13 years, which allows, for example, reliability intervals to be created or trade-offs to be made based on the overall risk of the asset (see next section).

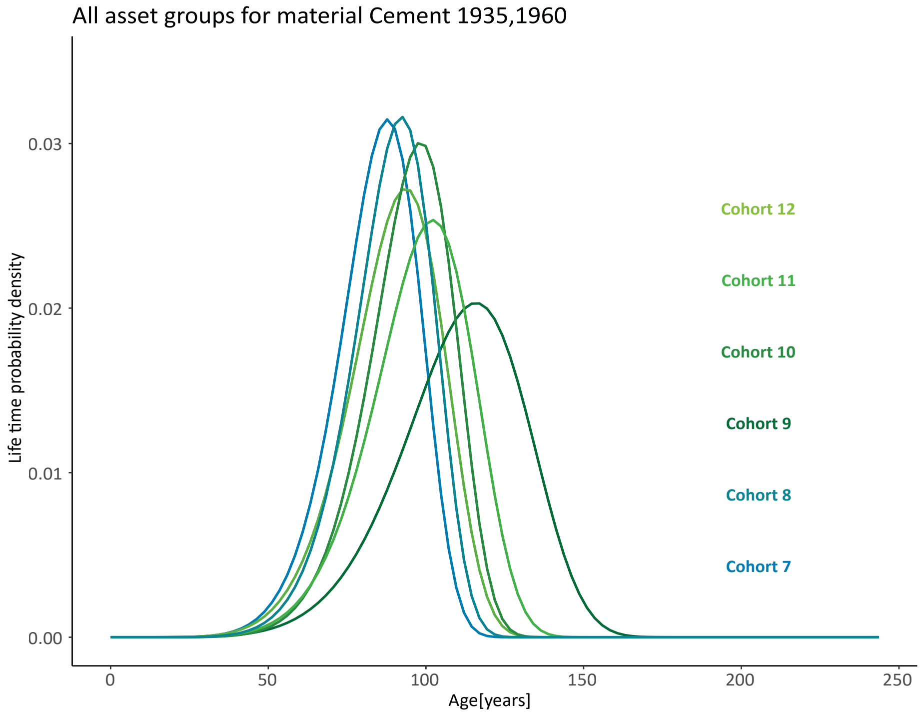

Figure 4. Probability distribution for the specific lifetimes of six asset cohorts

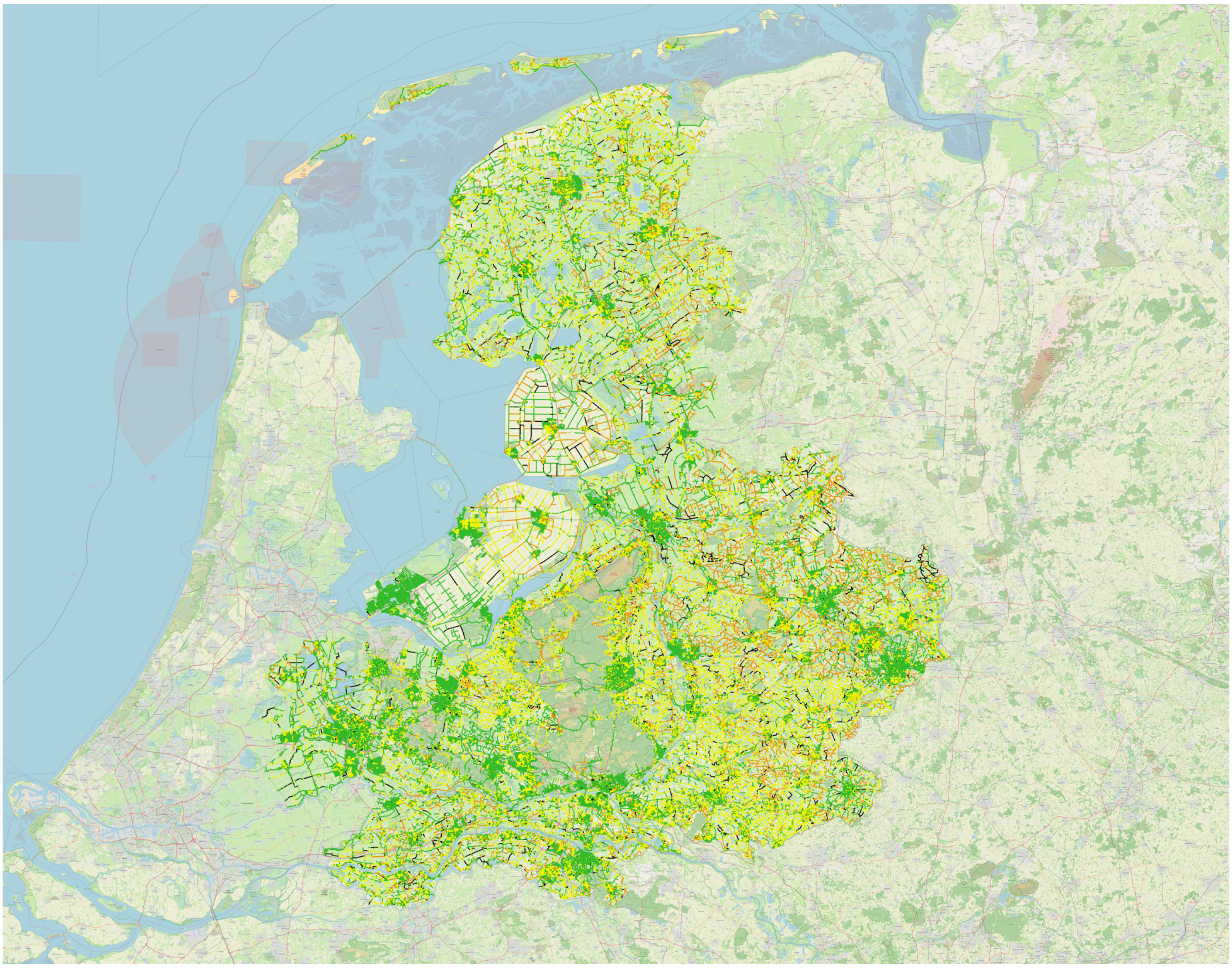

Figure 5. Map of the Vitens supply area in which the pipeline grid is coloured according to risk

From remaining lifetime to risk

Based on the above, the technical remaining lifetime can be determined for each asset unit. One of the dimensions of an asset's risk is 'Asset Health', the probability of failure. This can be calculated by dividing the remaining lifetime by the expected lifetime. However, the question is whether two pipes from the same cohort and with the same Asset Health need to be replaced at the same time.

To answer this question, the impact of failure ('Asset Criticality') needs to be considered. For example, a pipe in a metropolitan area or in front of a hospital may be replaced earlier than one in a rural area. In other words: based on the criticality of an asset, this asset can be replaced earlier than average, average or later than average. With this information, lifetimes can be extended in an informed way, whereas the opposite logic holds for highly critical pipelines. The combination of health and criticality results in a risk colour that reflects the timeframe and the type of decision that needs to be taken. This can be expressed in a matrix or represented graphically in a GIS tool (see figure 5).

From risk to planning

Vitens uses a risk model that calculates the probability of failure – and the effect of that failure – for all pipes, thus producing a risk score for each pipe. The results of the remaining lifetime mainly contribute to a more accurate determination of the probability of failure.

The risk model then prioritises pipes based on this risk score. This priority drives determining the required level of replacement and supports investment decisions.

The risk model is be used to maintain the performance of the pipeline network in the long term (100 years) and produces a predictable and balanced investment program.

With the improved insights from this study, the reliability of the risk model has improved and the replacement program is better substantiated.

Conclusions

Data-driven research as described above enables more informed and nuanced decisions to be made for the optimum operation of the pipeline grid. The insights obtained offer the ability to go beyond management based on averages.

The insights into the risk of individual pipes makes it possible to determine a budget level, from which a performance level can be obtained that is in line with a risk appetite acceptable to Vitens. In other words, it ensures that risk, cost and performance are properly balanced, both in terms of the overall grid and in terms of prioritising individual pipes. The methodology ensures transparent decision-making that can be communicated both internally and externally.

The main conclusions from this study are as follows:

- Sound data registration, both in terms of active as well as removed pipes, is crucial for a data-driven methodology. Being able to correctly link failures to pipes is the starting point for a deepdive into the remaining lifetime of the pipelines.

- External factors can play an important role in ageing behaviour: two assets of the same age and the same technical characteristics may show different failure behaviour due to their exposure to environmental factors.

- The insights from the methodology make it possible to design a more differentiated and accurate replacement policy. Thanks to machine learning, these insights are becoming better informed and will further reduce the uncertainty when it comes to determining the pipes' remaining lifetimes.

- Risk cannot be considered as an isolated element, but must be balanced with the required costs and the expected level of performance. There is no such thing as a risk-free network. However, insights can be provided into costs and required performance for each risk position.

Continue the Conversation

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