Improving the communication with stakeholders: the infrastructure degradation index and the infrastructure histogram

E. Estruch-Juan, E. Cabrera Jr., E. Gómez and R. del Teso

ABSTRACT

Water infrastructures are rapidly ageing without being properly replaced. Communicating the state of the network and the sector's needs to stakeholders is key for guaranteeing the sustainability of water and sewage systems. The infrastructure value index (IVI) is becoming a standard in the water industry as a communication tool; however, as a single value metric, it can mask key information.

The complementary use of the infrastructure degradation index (IDI) and the infrastructure histogram (H_I) can provide a better understanding of the network's state while maintaining the simplicity of the analysis needed for public dissemination. The IVI is focused on the value of the infrastructure, the IDI on its median remaining life. The H_I provides a detailed but simple picture of the network's remaining life, providing a clear idea of the magnitude of the investments needed in the future for maintaining the infrastructure.

Key words | infrastructure degradation index (IDI), infrastructure histogram (H_I), long-term planning, stakeholders' communication, water services

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HIGHLIGHTS

- Communicating the state of the network and the investment needs to stakeholders is key for guaranteeing the long-term sustainability of water and sewage systems.
- Communication with stakeholders requires effective and intuitive tools.
- The combination of the infrastructure value index (IVI) and the infrastructure degradation index (IDI) allows for a deeper comprehension of the network state and its rehabilitation needs.
- The infrastructure histogram (H_I) allows the analysis of the impact on the previous renovation strategies and forecasts the future needs in renovation.
- The sustainability of water infrastructures will only be reached if stakeholders recognise the importance of investing in water infrastructures following a strategic asset management approach.

INTRODUCTION

Water infrastructures are capital intensive and are designed for a long operational life (Alegre & Covas 2010). They are also generally buried, making the diagnosis of their state difficult and increasing their rehabilitation costs. The need of strategic asset management has become crucial for water supply and sewage utilities as infrastructures are gradually ageing without being properly replaced or rehabilitated (ASCE 2011). If the rehabilitation rates and approach of this issue do not change, then the water services could collapse in the medium to long term, as stated by H. Alegre (Nottarp-heim *et al.* 2015). It is therefore urgent that this issue is addressed.

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Water infrastructures are the most capital intense utility service (AWWA 2012). They have been in service for decades and the time to reinvest has arrived. However, customers are not aware of the elevated capital cost of the water services and, because they are hidden and the service is maintained, stakeholders are not aware of the criticality of their state (AWWA 2012). Finally, the fact that tariffs seldom cover capital costs (Pulido-Veláquez *et al.* 2014) make it difficult to reinvest in the network in order to maintain the quality of the service.

The water sector has a reactive attitude, in general, towards the infrastructure maintenance and renovation. This behaviour has severe consequences, such as the fact that the 40% of the European water networks need to be rehabilitated (Frost & Sullivan 2011) and that there is a requirement for the increasing renovation of the US water sector (ASCE 2011). There is a need to shift to a proactive point of view by using infrastructure asset management (IAM). Asset management could be described as the 'coordinated activity of an organisation to realise value from assets' as defined by the ISO 55000 standard (ISO 2014a, 2014b, 2014c). This is a broad concept that comprises all the assets an organisation has, and when the focus is on physical assets, then the term to IAM is used (Alegre & Coelho 2012).

In order to revert from this critical situation, it is essential to find the proper communication tools. The infrastructure value index (IVI) (Alegre 2008) is an index that reflects the rehabilitation needs of a network. This index summarises in a single value the state of the infrastructure given a specific moment in time. It simulates future scenarios that differ in the rehabilitation strategies implemented, and is a powerful long-term planning tool (Alegre Vitorino & Coelho 2014). In addition, it is a useful communication tool for stakeholders because it is easy and intuitive to interpret (Alegre *et al.* 2014; Alegre Vitorino & Coelho 2014). It can be calculated as follows:

$$IVI\ (t) = \frac{\text{Infrastructure current value}}{\text{Infrastructure replacement cost}} = \frac{\sum_{i=1}^{N}\left(rc_{i,t} \times \frac{rul_{i,t}}{eul_i}\right)}{\sum_{i=1}^{N} rc_{i,t}} \tag{1}$$

where t is the reference year when the index is calculated; N is the total number of assets considered; $rc_{i,t}$ is the cost of the asset i in the year t; $rul_{i,t}$ is the residual useful life of asset i in the year t; and $eul_{i,t}$ is the expected useful life of asset i.

The expected useful life of an asset is the average life for an asset since its moment of installation. This value depends on the asset's characteristics and working conditions. The residual useful life is the remaining life the asset is expected to have and is calculated as the expected useful life minus the actual age of the asset in the moment of the calculation.

This tool provides a value between 0 and 1. An IVI of 0 means that the infrastructure has no value left. A value of 1 belongs to a completely new infrastructure. Ideally, IVI values for a mature and well-maintained infrastructure should be between 0.4 and 0.6. Values over 0.6 belong to new infrastructures, old infrastructures in a growing phase or over-invested infrastructures. Values lower than 0.4 belong to old infrastructures with urgent need of rehabilitation (Alegre & Covas 2010).

IVI is a relatively new tool, with roughly 10 years of existence. However, due to the aforementioned benefits, it has been adopted by a significant number of utilities, especially in Europe. For instance, it has been included in the performance indicators system of the Portuguese water and waste regulator, ERSAR (ERSAR 2018). In Spain, the Spanish Water Utilities Association (AEAS) has included this tool in their new IAM manual of best practices (AEAS 2019).

However, IVI may not be enough, as a single metric, to assess the condition of the network. This work presents two supplementary tools, the infrastructure degradation index (IDI) and the infrastructure histogram (H_I), in order to obtain a more complete overview of the network's state and improve communication with stakeholders, without losing the simplicity of the IVI.

INFRASTRUCTURE DEGRADATION INDEX

The IDI represents the average remaining life of the network weighted by length (Cabrera Jr. *et al.* 2019). Remaining life is expressed as the expected working life minus the age of the pipe. It is expressed in years and provides a sense of urgency in network renovation. This index considers all pipes in the calculation, even those that have already exceeded their expected life but are still in service, regardless of whether they expired 5 or 25 years ago. The IDI is calculated as follows:

$$\text{Infrastructure Degradation Index } (t) = \frac{\sum_{i=1}^{N} L_i \times rul_{i,t}}{\sum_{i=1}^{N} L_i} \quad (2)$$

where t is the reference year when the index is calculated; N is the total number of pipes considered; L_i is the length of the pipe i, $rul_{i,t}$ is the residual life of the pipe i in the year t. If a pipe has expired its life, $rul_{i,t}$ will be negative and will account for the amount of time the residual life of the pipe has been exceeded.

IDI values can be either positive or negative. The maximum value for IDI would be expected when a network is completely new. In this case, IDI would be the mean expected life of new materials, weighted by length. Values of a well-maintained average network would be between 25–30 years, which coincide with half of the expected remaining life of the materials installed.

If IDI is equal to zero, this means that the average weighted residual life of the network is zero. In this situation, although there can be completely new pipes, the weight of those with an expired working life is more important, making the balance zero. This situation is not recommended because it suggests that the renovation needs are urgent and cannot be postponed. In this situation, not renewing the network entails a serious risk in the quality of the service and its sustainability. Negative values of IDI would further increase this problem.

The life expectancy of a pipe depends of several factors, such as material, diameter, working condition, soil characteristics, etc. Therefore, the life expectancy depends, on the one hand, on the pipe's characteristics and, on the other, on the utility's context. It is recommended that life expectancy values are estimated from the utility's historic registers because the IDI measure will be more accurate. Unfortunately, these data are seldom available, and thus values are obtained from the published literature (ISO 2016; Covas *et al.* 2018).

An interesting feature of this tool is that it includes the length of those pipes with their expected life expired. However, in IVI calculations an asset with its expected life expired has a cost of zero, regardless of when this asset expired because the tool is focused on the cost of the infrastructure. Therefore, IVI detects the percentage of network expired, but it is unable to detect if these pipes expired 2 or 20 years ago. From a mathematical point of view, the IVI value would be the same. IDI is better at assessing networks with assets that should have been replaced long ago.

The consequence of this fact is that the sensibility of IDI is constant during time. However, IVI loses sensibility when approaching lower values of the index (below 0.40) because the line becomes quasi-asymptotic towards values of IVI = 0. This occurs because in IVI calculation, pipes with expired life are zero in the numerator of the IVI equation. Therefore, the tendency of the IVI changes and its slope becomes close to an asymptotic line, decreasing slowly towards zero.

The IDI aims to complement the IVI as a public communication tool. IDI is focused on time and gives a sense of urgency for renovation expressed in years. IVI is focused on value. The joint analysis of both indices provides a more complete picture of the state of the infrastructure, while maintaining the simplicity of the tools.

THE INFRASTRUCTURE HISTOGRAM (H_I)

The H_I represents detailed information about the network state in a simple and intuitive way. This tool represents the remaining life of all pipes in the network classified by their percentage in length. Figure 1 displays an H_I. The horizontal axis shows the remaining life of pipes. The bars represent the length of pipes in percentages, classified by their expected life. Finally, the grey area highlights pipes with an expired estimated life (negative values of remaining life). This chart allows for a quick assessment of the state of the network and the urgency of the renovation strategy.

The flatter the H_I, the better the network is managed because it means that reinvestments will be constant over time. Peaks in the H_I could indicate high investment periods where significant parts of the infrastructure was built. Large peaks are therefore undesirable because they point out important punctual reinvestments. Isolated peaks could also point to data lagoons, especially in old networks with significant uncertainty concerning when the pipes were laid out. In these cases, it was usual to estimate an age for them.

The H_I of the network displayed in Figure 1 shows a network without large peaks of investment. This network has an IVI of 0.35 and an IDI of 19.70 years, which indicate a network in poor condition.

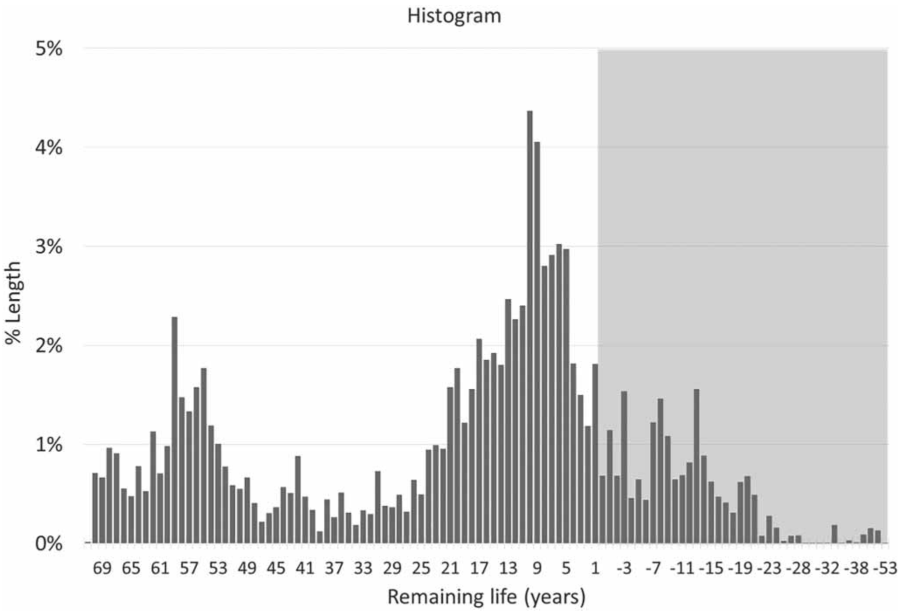

Figure 1 | The H_I.

The IDI value indicates a network that is slightly lower than the values expected in a well-maintained network (25–30 years) and therefore needs some renovation. The IVI is, nevertheless, in the undesired area (lower than 0.40). In this case, the low IVI value might be misleading because of the materials that constitute the network. This network is mainly built using materials with a long-life expectancy, such as ductile iron. The IVI is calculated as a cost-based ratio between the remaining life and the expected life. The network in Figure 1 still has almost 20 years left in average (IDI value), but the IVI value is low (as the denominator is quite large due to the large life-expectancy of materials).

A closer look to the figure explains why the network is in poor condition: it has a section with its life already expired although, it is not a large percentage. However, what does decrease the value of both IVI and IDI indices is the percentage of pipes that is about to expire.

As has been demonstrated, the IVI and IDI values provide a good starting point in assessing the network's state, and the H_I complements both tools.

H_I can be further improved by showing groups of pipes with a selected diameter range or material, as shown in Figures 2 and 3. This option enables a deeper analysis where the criticality of the infrastructure can be further analysed. For instance, it is important to locate large diameters or the percentage of obsolete materials, such as asbestos cement, that are expensive to replace.

The detailed histograms are useful tools for stakeholders' communication because they allow easy interpretation and analysis of the specific network state and its investment needs. They also enable investigation of the different factors (type of material, range of diameters, etc.) that are involved in the renovation strategy.

CONCLUSIONS

This work analyses the use of three tools to improve communication with stakeholders concerning the state of the network and its rehabilitation needs.

The IVI is focused on the investment needs, whereas the IDI emphasises the state of the infrastructure and the urgency of the intervention. The combination of these two indices allows a deeper comprehension of the network state.

The H_I provides a further in-depth analysis and increases the information given by the two previous measures. It analyses the impact of the previous renovation strategies and forecasts the future needs in renovation. This tool classifies the network by its remaining life and details the length of pipes of a specific material or diameter. Both

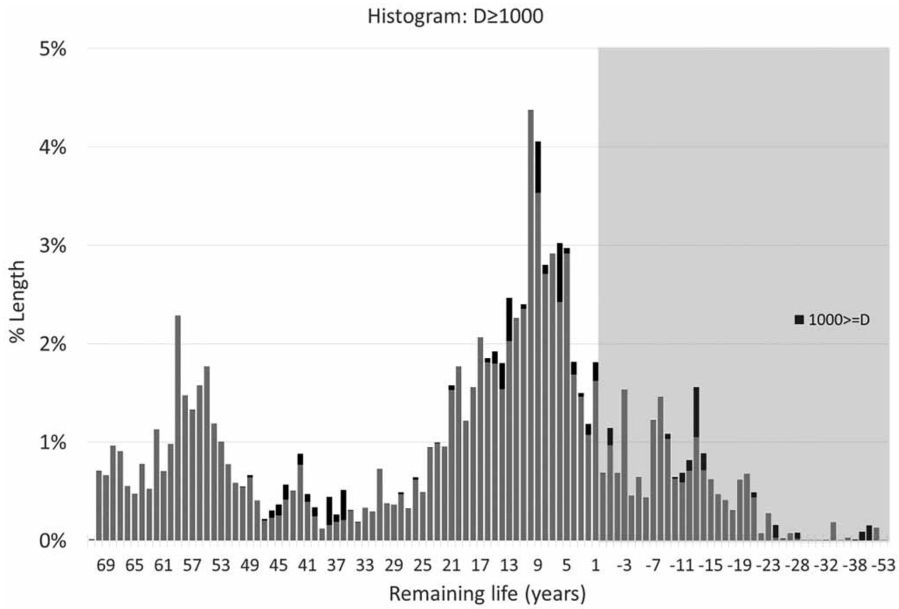

Figure 2 | The infrastructure histogram displaying the length of pipes with a diameter bigger than 1,000 mm;.

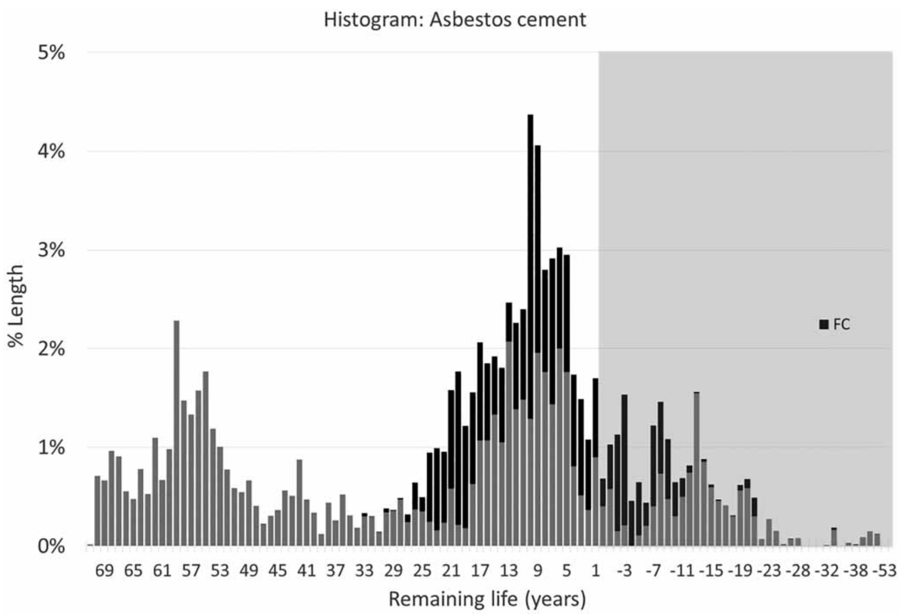

Figure 3 | The infrastructure histogram displaying the length of pipes made from asbestos cement.

characteristics have a direct impact in the cost and the selected renovation strategies.

The potential use of these three tools is broad. They could be used, for instance, in benchmarking projects to assess the sustainability of the water networks and promote their improvement and excellence. Other uses could be as regulatory tools to supervise the sustainability of water infrastructures. In fact, the Portuguese Water and Waste Regulator (ERSAR) is currently using the IVI in its sunshine regulation initiative (ERSAR 2018).

IVI, IDI and H_I allow stakeholders to understand, in a simple manner, the magnitude of the problem. They will also be aware of the need for a long-term plan of infrastructure asset management. The sustainability of water infrastructures will be only reached if stakeholders recognise the importance of investing in water infrastructures and follow a strategic asset management approach. It is important to bear in mind that these tools are for communication and do not intend to substitute detailed analysis of performance, risk and costs.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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